

Sediment Control Plan for the Blackstone River

Massachusetts Dept. of Environmental
Quality Engineering, Boston

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A SEDIMENT CONTROL PLAN

FOR THE

BLACKSTONE RIVER

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July, 1981

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Sediment Control Plan
Blackstone River

I.

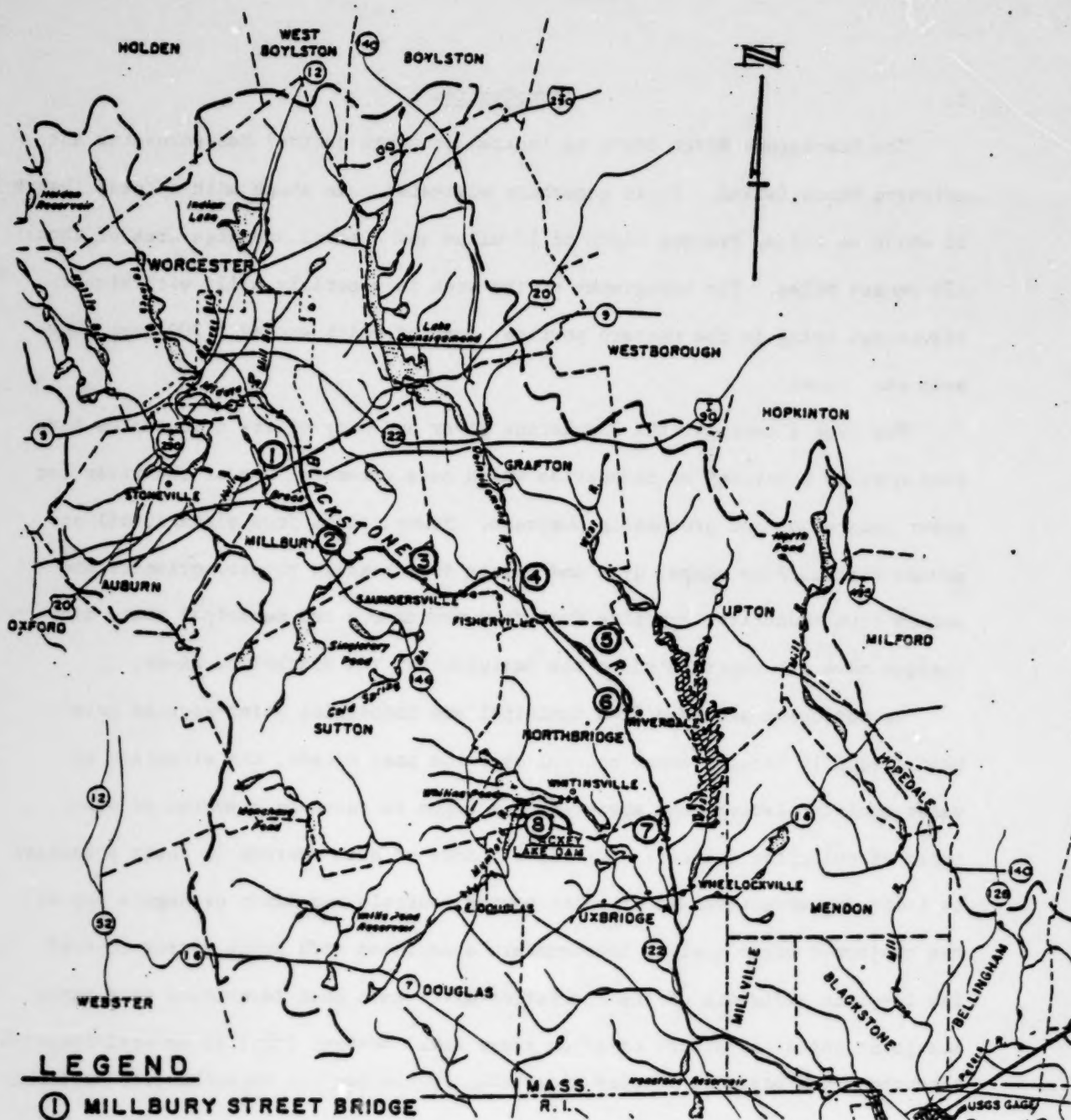
Introduction

The Blackstone River Basin is located in south central Massachusetts and northern Rhode Island. It is generally elongated in shape with a total length of about 44 miles, average width of 12 miles and a total drainage area of about 476 square miles. The topography of the area is generally hilly with higher elevations lying in the western portion, some of which exceed 1,300 feet above mean sea level.

For over a century, the Blackstone River and many of its tributaries have been host to a variety of industries which made extensive use of the river for power generation and processing purposes. Heavy metals from platers, oil and grease from machine shops, dyes and prints from textile plants, organics and metals from tanneries, organics from food processors and municipal waste discharges have all contributed to the pollution of the Blackstone River.

As pollution problems from municipal and industrial point sources have been gradually brought under control over the past decade, the attention of water quality planners and engineers has begun to focus on a myriad of other types of pollution sources. The significance of such sources is their potential to limit the effectiveness of point source controls and limit or negate any of the projected water quality improvements associated with point source control. The in-place sediments of the Blackstone River have been identified as a major non-point pollution source based on heavy metal content found at several locations throughout the basin in studies undertaken by the Central Massachusetts Regional Planning Commission 208 study.

The objectives of this project are to determine the levels of heavy metals in sediment at several representative or critical locations in the Blackstone



LEGEND

- ① MILLBURY STREET BRIDGE
- ② McCRACKEN ROAD BRIDGE
- ③ SINGING DAM
- ④ FISHERVILLE POND
- ⑤ NORTHBRIDGE MILL DAM
- ⑥ RIVERDALE MILL DAM
- ⑦ RICE CITY POND
- ⑧ LACKEY POND

REPORT ON BLACKSTONE RIVER SEDIMENT CONTROL AND REMOVAL

FIGURE I-1

SITE LOCATION PLAN

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✓
River Basin; determine the volume of sediment contaminated; assess the impacts of the sediment on the ecology of the river ; describe the alternative methods of treatment and/or removal of sediments; assess the impacts of the control alternatives; and prescribe a program to control or eliminate pollution from in-place sediment deposits.

In order to address these objectives, eight sites were selected for detailed investigation. These are shown in Figure I-1. Seven sites are located on the main stem of the Blackstone River. The eighth site is located on the Manford River, a major tributary to the Blackstone River. The consultant firm of C.E. Maguire, Inc. was employed to conduct the site investigations and the assessment of control alternatives, costs and impacts. The following sections of this report describe the investigations conducted in conjunction with this program, the conclusions reached based on information gathered during the investigations, an outline of control alternatives, costs and impacts and recommended elements of a sediment control plan.

II. Site Investigations

A. General

A wide range of sampling and testing methods were employed to adequately assess the quantity and quality of the sediments at each location. Each site was investigated with a hand auger. Samples were taken continuously with depth using a 1 inch diameter spoon sampler to refusal at the bottom of sediments, usually a compact sand, gravel, or hard bottom. The samples were placed and sealed in ziplock plastic bags and brought to DEQE Laboratory in Westborough at the end of each day (within 24 hours of sampling) where they were stored in a refrigerated room until the analysis was accomplished. Generally, each location was augered a second time in order to obtain sufficient sample for testing.

In addition to hand auger borings, probes were taken using a 1/2-inch diameter steel rod. The rod was pushed until the sediments were penetrated as above.

Subbottom profiling was undertaken at three sites. It was performed by D. Richard Blidberg, Project Research Engineer of the University of New Hampshire Marine Program. The equipment utilized was O.R.E. (Ocean Research Equipment) Subbottom Profiler, consisting of a variable frequency transducer and a variable frequency transceiver and recorder. As the boat traveled over the site, a continuous bottom profile was printed and the location of the boat was noted on the printout at regular intervals. Depth to bottom was readily depicted on the printout. The frequency was modulated at intervals to penetrate soft bottom sediments. No appreciable thickness of bottom sediments was found at the three sites investigated (Lackey Pond, Fisherville Dame, and Singing Dam). Other sites could not be investigated due to the shallow water depth and the potential damage to O.R.E. equipment.

Grain size, moisture content, and organic content (% volatiles) were determined for each foot of depth penetrated for all borings (by DEQE Westborough Laboratory). The procedure used was to determine moisture content and percent organics from representative samples, and then grain size was run on the remaining material. Organic content was determined by heating an oven dried sample (105°C) in a Muffle Furnace at 550°C to constant weight. A summary of the soil properties is given in Appendix A.

Chemical testing was performed at the DEQE Lawrence Laboratories. Total concentrations of heavy metals, i.e., cadmium, chromium, copper, lead, nickel, zinc, arsenic, aluminum and iron were determined by sulphuric acid digestion followed by perchloric acid digestion. The analysis was performed on a mass spectrometer. All top and bottom samples for each boring (65) were analyzed. Descriptions of each site and a summary of the results of investigations undertaken at each site follow in sections B-I. Remaining sections describe other sampling and analysis programs conducted in conjunction with this project.

B. SITE NO. 1 - MILLBURY STREET BRIDGE

1. Description of Topography

The area immediately adjacent to the Millbury Street bridge consists of a 60 to 100 foot wide river bed. Depth of water is up to 5 feet on either side of the river. A low relief (6" high) gravel bar about 60 feet long is located about 100 feet downstream from the bridge, and a sand bank about 70 feet long lies immediately adjacent to the bridge. Bank erosion was observed upstream of the bridge and immediately beneath it. Plan and profiles are presented in Figure II-1.

The bridge acts as a constriction to the river at this location and has probably deepened the river beneath the bridge, resulting in a depositional mode downstream. No fine grained soft sediments are found

within the study area at this site. Prominent features include a sand bank downstream of the bridge which was probably deposited by past flooding and as a result of the bridge constriction. A gravel bar in the downstream center of the river may also have been the result of the bridge constriction.

The banks of the river are quite steep in this location, and the adjacent land would not be affected by normal spring flooding. Sediment accumulation if any, is restricted to the vicinity of the river banks and stream bed.

No vegetative cover was noted on the gravel bar or sand bank. Trees and grasses were growing on the sides and top of the river banks.

2. Geotechnical Investigations

A total of two hand auger borings were taken at Site No. 1. One was located on the sand bank and the other on the gravel bank located mid-river (Boring No. 1-1 and 1-2, respectively). Boring 1-1 was accomplished to a depth of 7 feet. The material encountered consisted of coarse to fine sand with a trace of silt (organics) and gravel. The material sizes were relatively uniform with depth indicating uniform conditions of deposition. Low amounts of silt and organics are indicative of the flow velocities. The water table was formed at EL 414⁺, which corresponded to the river level. Refusal was on gravel. Boring 1-2 was accomplished by hand shovel due to the nature of the material. Penetration was 6 inches in gravel. Two samples were analyzed for grain size. Both samples consisted of gravelly sands with a trace of silt (organics). The low percentage of silt and high gravel content again are indicative of moderate to high depositional water velocities.

The results of the auger borings indicate the following subsurface stratification starting from the ground surface as follows: a discon-

tinuous layer of loose sand up to 7 feet thick overlying; and a continuous layer of compact gravelly sand underneath.

3. Chemical Test Results

Chemical tests were performed on two samples at different depths from the downstream sandbar on the right river bank. Most metals occurred in similar concentrations in the top sample (1 foot depth) and the bottom sample (7 feet). Their occurrence in mg/kg approximately was: Al (7000), Cd (10), Cr (90), Pb (420), Ni (60), As (13). Iron was found in the bottom sample at a total concentration of 63,000 mg/kg, roughly three times its concentration in the top sample. Copper and zinc both were half an order of magnitude higher in the lower sample (1550 mg/kg and 1070 mg/kg).

Two additional tests were performed on shallow samples (1 foot depth) from the gravel bar in the middle of the Blackstone River downstream of the bridge. With the exception of copper (420 mg/kg) and aluminum (8000 mg/kg), all metals in these samples occurred at nearly twice the concentrations found in the shallow sandbar sample, despite the existence of the coarser soil material in the gravel bar.

Statistically, the four samples contained total metal concentrations which occurred at a coefficient of variance of between 30% and 85%. (Coefficient of variance is equal to the ratio of mean value and standard deviation.) The narrow grouping around the mean values may indicate a spatially uniform metal content of the sediments within the reach of Site No. 1. Table II-1 contains the results of the bulk sediment analysis.

4. Quantification of Materials

An estimate of volume of sediments encompassing the sand bar along the bank downstream of the bridge and the gravel bar also downstream is as follows:

Area .16 acre
Volume of Sediments 250 cu. yds.

Due to their position, location, and physical content, these sediments should not be subject to normal stream erosion.

C. SITE NO. 2 - MCCracken ROAD BRIDGE

1. Site Description

The area adjacent to the bridge consists of an 80 to 100 foot wide stream bed. Upstream of the bridge is a rounded gravel bar approximately 60 feet wide and 200 feet long. The upstream west bank is steep (7 feet high) and eroded at the water line. The upstream east bank is lower in relief (3 feet high) and only slightly eroded. The downstream banks are steep (20 feet to 25 feet high) and are protected by stone riprap. Plan and profiles are presented in Figure II-2.

For this site also, the bridge acts as a constriction to the river and noticeably deepens adjacent to and under the bridge. Consequently, little, if any, fine grained sediments were found at this site. Gravels and coarse sands are exposed in the river bed and adjacent banks. With the exception of the east bank, all of the banks are steep and high and serve to contain the river in times of normal flood.

Several tufts of water grass were observed on the gravel bar at locations where finer soils are trapped downstream of large stones. Generally, the bar was clean of vegetation. The upstream banks were eroding. Small trees, brush, and grass generally cover the top of the bank and surrounding area. Man-made fills are located over portions of the site. Some dumping of miscellaneous fills has occurred along the upstream portions of the site.

2. Geotechnical Investigations

A total of three hand auger borings were taken at Site No. 2. One was located in the gravel bar upstream of the bridge (Boring 2-2) and the others on the upstream and downstream east bank of the river (Boring 2-1 and 2-3). Boring 2-1 was accomplished to a depth of 7 feet. The material encountered consisted of fine to coarse sands, silty and gravelly for the top 2 feet, then a 4-foot thickness of gravelly coarse sand with a trace of silt. Refusal was hard bottom. Organic content ranged from 4% to 7%, except for the bottom foot which was 0.5%. The range of grain sizes was fairly uniform throughout the full depth. Boring 2-2 was accomplished to a depth of 2 feet in sand and gravel with a trace of silt. Organic content decreased from 5% to 2% with depth. Refusal was on gravel. Boring 2-3 was accomplished to a depth of 1 foot in fine to coarse sand with a trace of gravel and silt. Organic content was in the same range (7%) as sample 2-1.

Again, as in Site No. 1, the relatively low silt and high gravel contents of the samples are indicative of moderate to high depositional water velocities.

The results of the test borings indicate the following generalized subsurface stratification starting from the ground surface:

- (a) A discontinuous layer of fine to coarse sand, and coarse to fine gravelly silt with a trace of organics up to 6 feet thick.
- (b) A discontinuous layer of fine to coarse sand, gravelly and silty with a trace of organics.
- (c) A discontinuous layer of sand and gravel with a trace of silt and organics up to 2 feet in thickness.

Refusal was on hard gravelly bottom. Water levels were river levels.

3. Chemical Test Results

A total of five chemical tests were performed on samples from three different boring locations. A general comparison with Site No. 1 shows that zinc and lead on the average occur at lower levels. However, cadmium (a nonessential metal) was found at very high concentrations in the deeper samples, (1000 mg/kg).

Again, samples taken from fine grained material (the sandbank on the westerly upstream side) did not show significantly higher metal concentrations than samples from the gravel bar in the middle of the river upstream of the McCracken Road Bridge.

Average results in mg/kg were: As (11), Al (7000), Cu (270), Fe (23,000), Pb (250), Ni (70), Zn (100). With the exception of cadmium, zinc and nickel, all metals distributed over the sampling sites have a coefficient of variance of between 30% and 80%.

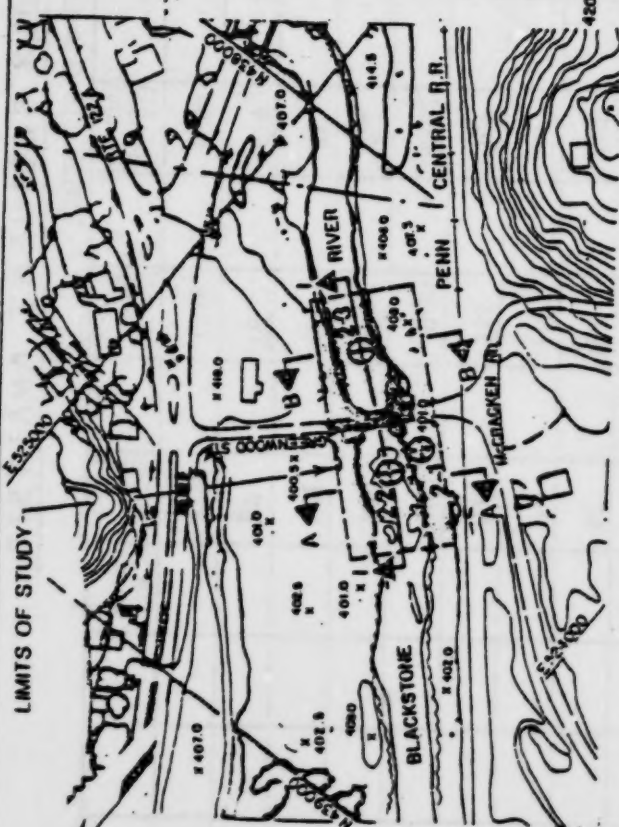
There was no predictable distribution with depth. Table II-2 contains the results of the bulk sediment analysis.

4. Quantification of Materials

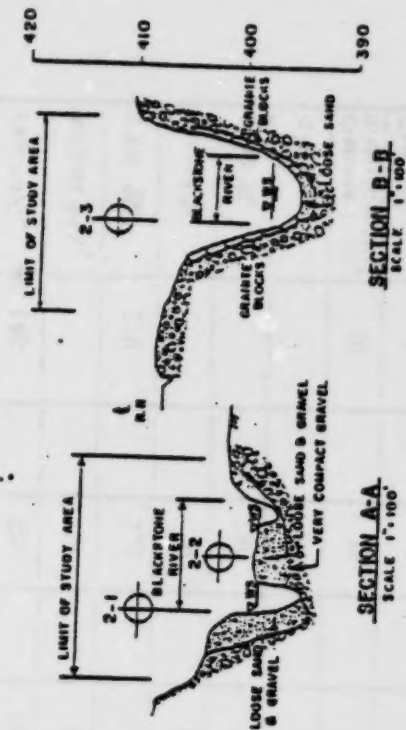
An estimate of volume of sediments was made encompassing the sand and gravel bar in the main channel and the sand banks along the unprotected upstream portion of the site. The area and volume are given below:

Area	0.43 acres
Volume	4700 cu.yds.

Due to their position, location, and physical content, since these sediments are generally coarse, they should not be subject to normal stream erosion.



NOTE:
1. SEE FIG. NO. 1-1 FOR GENERAL NOTES AND LEGEND.



SITE NO. 2 - GREENWOOD STREET BRIDGE
PLAN AND PROFILE
BLACKSTONE RIVER SEDIMENT STUDY
FIG. NO. 11-2

PLAN
SCALE 1" = 200'

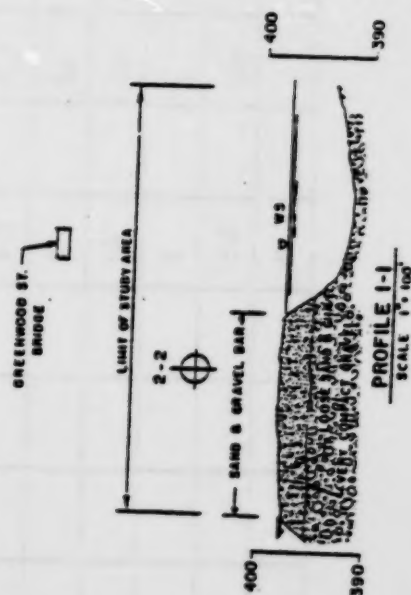


TABLE II-2 : BULK SEDIMENT ANALYSIS

SAMPLE PARAMETERS	CMRPC 208 Study	SITE NO.2 - GREENWOOD ST. BRIDGE					2-1-1 Bank Adj.	2-1-7 Bank Above VL	2-1-7 Above VL Riv	2-2-2 Bank Mid Riv.	2-3-1 Bot. of Below VL Div	Bank Div
Aluminum mg/kg							9210	8180	4933	4621	8442	
Cadmium mg/kg	9.2		2.2	98	6.9					90	19	
Chromium mg/kg	130		43	89	92					5.9	178	
Copper mg/kg	200		226	394	207					197	328	
Iron mg/kg			29900	20700	20700					18700	23,450	
Lead mg/kg	150		322	138	138					226	460	
Nickel mg/kg	40		30	33	22					207	52	
Zinc mg/kg	140		122	148	109					85	28	
Arsenic mg/kg			17	12	7					6	14	
TVS %	3.9		5.8	0.5	4.6					1.7	7.1	
Gravel %			9	12	47					48	7	
Sand %			80	81	51					51	87	
Silt %			11	7	2					1	7	
Distance from Bridge (0.0m) [ft.]	70		35	35	100					100	125'	
Depth of Sample [ft.]	.5		1	7	1					2	1	

D. SITE NO. 3 - SINGING DAM

1. Description of Topography

Singing Dam consists of a masonry granite block overflow structure about 100 feet long and 12 feet high. The water level behind the dam is approximately at Elevation 344[±]. During periods of normal flow, water levels remain within the readily noticeable stream channel.

Extensive marshes are located on the southside of the Blackstone upstream of the dam. Generally, ground water is close to the ground surface. Elevations are several feet higher on the north bank of the river and gently sloping up away from the river. The above area is grass and shrub covered on this side of the river. River channel width ranges from about 80 to 100 feet, the wider portion being closer to the dam. Moderate erosion was observed along the banks of the river. The marshy area consists of low relief bars and banks up to 350 feet wide. A large bar, 1200 feet long and 200 feet wide, is located about 2400 feet upstream of the dam.

During periods of flooding, the adjacent marsh and portions of the meadow area may be inundated. Fine grained sediment build-up should be relatively slow in the marsh and bar areas since these are not permanently below the water table. The higher water velocities may tend to scour the stream bed during periods of flooding.

Marsh reeds, grass, shrubs, and small trees are prevalent in the marsh and bar area. Grass and shrubs are also abundant on the north bank of the river. A total of 24 different plant species were identified. Plan and profiles are presented in Figure II-3.

2. Geotechnical Investigation

A total of four hand auger borings were taken at Site No. 3. Two borings (3-1 and 3-4) were located in the large bar 1400 feet up-

stream of the dam and two borings (3-2 and 3-3) were located in the marshy area to the south of the river.

Boring 3-1 (upstream bar) was accomplished to a depth of 2 feet. The material consists of gravelly fine to coarse sands with a trace of silt for the first foot, and silty fine to coarse sands. Organic and silt content are considerably higher for this site compared to Sites No. 1 and 2 (30% and 35%, respectively for the bottom foot. The top foot being the exception as far as silt content 4% and 20% organics). The organic content falls outside the silt content in the top foot sample.

Boring 3-2 (marsh adjacent to dam) was accomplished to a depth of 3 feet. The material consists of gravelly, silty coarse to fine sands with considerable organic content (23% to 35%). Generally, gravel sizes decreased with depth and silt and organic content increased with depth (40%, 28%, and 21%; and 11%, 22%, and 25%).

Boring 3-3 (mid-marsh) was accomplished to a depth of 3 feet. The material consists of gravelly, silty coarse to fine sands. Again, organic content was considerable (12% to 45%). The organic content falls outside the silt content for all three samples. Generally, silt and organic content increased with depth for the top 2 feet and decreased for the bottom foot, (18%, 32%, and 2%; and 37%, 45%, and 12%, respectively) while gravel content decreased or remained constant with depth (25%, 12% and 12%).

Boring 3-4 (tip of upstream bar) was accomplished to a depth of 4 feet. The material consists of gravelly, silty, coarse to fine sand. Organic content was high (20% to 27%). Organic and silt content were relatively constant with depth (27% and 20%, and 22% and 25%, respectively).

Depositional water velocities were significantly lower for this site due to the relatively wide flood plain and the dam downstream resulting in higher silt and organic contents of the soil samples. The continued presence of gravel sizes is indicative of a fairly wide range of water depositional velocities over the site. The sands deposited in the upstream bar were finer and less consistent in sizes than those deposited in the marsh.

The results of the test borings indicate the following generalized subsurface stratification starting from the ground surface:

- (a) A discontinuous layer of silty, gravelly, fine to coarse sand with some organics (up to 2 feet thick).
- (b) A discontinuous layer of silty, gravelly, coarse to fine sand with some organics up to 3 feet in thickness.

Refusal was on hard gravelly, cobbly bottom. Water levels in the boreholes were river levels.

A total of 32 probes were accomplished within the study area. The probes indicated up to 10 feet or more of soft mud. The probes indicated the hard bottom to be considerably deeper in the area closer to the dam than derived from the hand auger borings. Consequently, the volume of sediments is based on thickness as determined by the probes. The sediments consisted of soft silt as well as sandy, clayey layers.

3. Chemical Test Results

Eight samples from four boring sites were tested. A marked increase from Sites No. 1 and No. 2 in total metal contents was found, independent of location and depth of the sample origins. Expressed in mg/kg the average metal concentrations for Site No. 3 were: As (35), Al (15,000), Cd (50), Cr (500), Fe (51,000), Pb (1,100), Ni (110), Zn (1,150). Particularly, the metals cadmium, arsenic, chromium, lead and zinc occurred

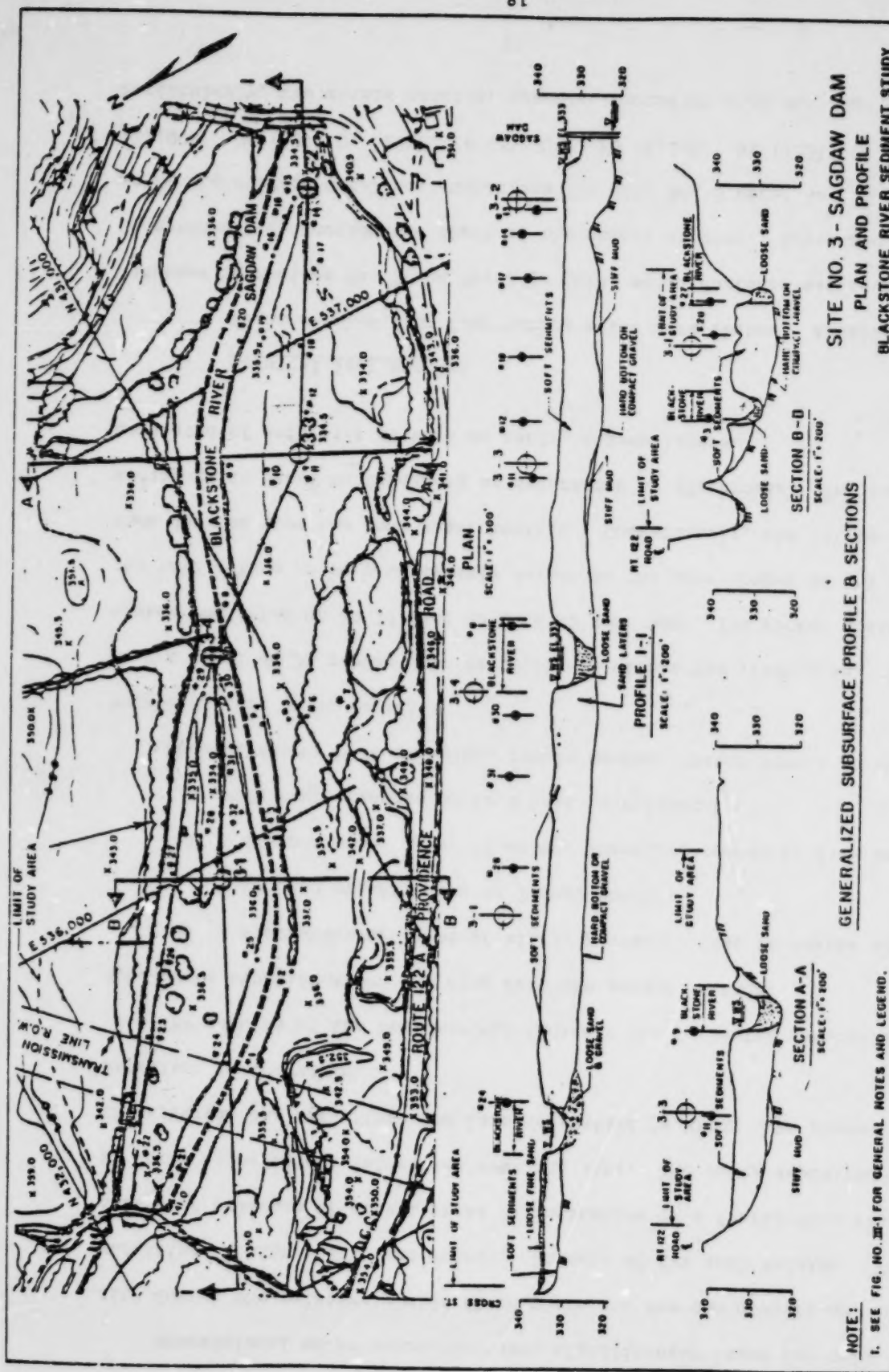


TABLE II-3 : BULK SEDIMENT ANALYSIS

SAMPLE PARAMETERS	CMRPC 208 Study	SITE NO. 3 - SINGING DAM							3-4-I Tip of Bar	3-4-2	
		3-1-1 Mid Bar	3-1-2	3-2-1 Rip of Marsh	3-2-3	3-3-1 Mid Marsh	3-3-3				
Aluminum mg/kg											
Cadmium mg/kg	<u>100</u>	<u>36</u>	<u>11</u>	<u>75</u>	<u>117</u>	<u>27</u>	<u>11</u>		<u>57</u>	<u>48</u>	
Chromium mg/kg	<u>750</u>	<u>258</u>	<u>124</u>	<u>1456</u>	<u>868</u>	<u>280</u>	<u>94</u>		<u>484</u>	<u>412</u>	
Copper mg/kg	<u>1300</u>	<u>480</u>	<u>321</u>	<u>1447</u>	<u>2926</u>	<u>2682</u>	<u>1242</u>		<u>555</u>	<u>735</u>	
Iron mg/kg											
Lead mg/kg	<u>980</u>	<u>445</u>	<u>279</u>	<u>1262</u>	<u>1951</u>	<u>1399</u>	<u>986</u>		<u>1044</u>	<u>1344</u>	
Nickel mg/kg	<u>2900</u>	<u>117</u>	<u>47</u>	<u>145</u>	<u>156</u>	<u>100</u>	<u>46</u>		<u>152</u>	<u>116</u>	
Zinc mg/kg	<u>1700</u>	<u>902</u>	<u>352</u>	<u>903</u>	<u>2439</u>	<u>1632</u>	<u>986</u>		<u>949</u>	<u>986</u>	
Arsenic mg/kg	<u>5</u>	<u>19</u>	<u>12</u>	<u>39</u>	<u>69</u>	<u>65</u>	<u>29</u>		<u>23</u>	<u>28</u>	
TVS %	<u>18.0</u>	<u>18.7</u>	<u>29.5</u>	<u>23</u>	<u>35.5</u>	<u>37</u>	<u>12.1</u>		<u>27.2</u>	<u>20.7</u>	
Gravel %		<u>20</u>	<u>4</u>	<u>40</u>	<u>21</u>	<u>25</u>	<u>12</u>		<u>25</u>	<u>17</u>	
Sand %		<u>76</u>	<u>61</u>	<u>49</u>	<u>54</u>	<u>57</u>	<u>86</u>		<u>53</u>	<u>58</u>	
Silt %		<u>4</u>	<u>35</u>	<u>11</u>	<u>25</u>	<u>18</u>	<u>2</u>		<u>22</u>	<u>25</u>	
Distance from Bridge (Down) [ft.]	<u>70</u>	<u>1800</u>	<u>1800</u>	<u>175</u>	<u>175</u>	<u>300</u>	<u>300</u>		<u>1300*</u>	<u>1300*</u>	
Depth of Sample [ft.]	<u>.5</u>	<u>1</u>	<u>2</u>	<u>1</u>	<u>3</u>	<u>1</u>	<u>3</u>		<u>1</u>	<u>2</u>	

(throughout the sampling points) at enormously high levels.

Again, a coefficient of variance between 40% and 90% suggests somewhat uniform conditions for the whole site. While an increase by a factor of two seems to be detectable as one compares the upstream samples 3-1 and 3-4 with the samples taken closer to the dam(3-2,3-3), no predictable trend with depth was observed.

It has to be noted that at this site considerable amounts of organics were encountered. Volatile solids were found at concentration of between 12% and 40% (percentage of dry weight of sample). Their presence in the soil may be accountable for the relatively high metal concentrations. Table II-3 contains the results of the bulk sediment analysis.

4. Quantification of Materials

An estimate of volume of sediments was made encompassing the deposits on the north and south banks and the basin of the river. Area and volume are given below:

Area	27.8 acre
Volume of Sediment	260,000 CY

E. SITE NO. 4 - FISHERVILLE DAM

1. Description of Topography

Fisherville Dame is located below the confluence of the Blackstone and Quinsigamond Rivers and consists of an earth fill and granite block structure 12 feet high. The spillway is an overflow type and is 200 feet long. The water level behind the dam is approximately at Elevation 269⁺. Extensive bars and marshes are located adjacent to the dam and considerable channeling by the Blackstone River is apparent in this area. North of the Blackstone River lies much open water where the Quinsigamond River flows into Fisherville Dam. The height of the abutment indicates that at one time the dam was 7 to 8 feet higher than at present.

Extensive marshes are located adjacent to the Blackstone River and the dam. Generally, groundwater is at or close to the ground surface in the above areas. A 40 to 300 foot wide channel is located along the east bank of Fisherville Pond connecting to the Blackstone River and to the main pond. Water covered areas amount to approximately 45% of the total study area. The area surrounding Fisherville Dam consists of moderate to steeply sloping hills up to 100 feet high which ring the pond.

Normal flooding is expected to inundate the marsh areas adjacent to the Blackstone River. With the dam at its present level, fine grained sediment build-up should be relatively slow in the marsh area. Flood water, however, might tend to scour the streambed. A hydrographic survey was conducted in the water covered areas. The survey indicated an 8 to 10 foot water depth in the channel areas and lesser depths back up the Blackstone, and towards the Quinsigamond River.

Marsh reeds, grass, and shrubs are prevalent in the marsh and bar areas. A total of 28 different plant species were identified. Plan and profiles are presented in Figure II-4.

2. Geotechnical Investigations

A total of nine hand auger borings were taken at Site No. 4. Three borings (4-1, 4-2, 4-4 and 4-7) were taken in water covered areas. Two borings (4-3 and 4-9) were taken in marsh area south of the Blackstone River; two borings (4-5 and 4-6) were taken on bars within the river and one boring was taken in the marsh area to the north of the Blackstone River. All borings hit refusal at relatively shallow depths (1 to 2 feet).

Boring 4-1 and 4-2 were taken adjacent to the dam in the channel.

The borings were accomplished to a depth of 1 foot. The material consists of silty fine to coarse sands. Organic silt contents were moderate 13% and 7%, and 18% and 12%, respectively. Borings 4-4 and 4-7 were taken at the Blackstone River and channel juncture and at the middle of Fisherville Pond. The borings were accomplished to a depth of 1 foot. The material consists of silty coarse to fine sand and sandy fine gravel with a trace of silt. Silt and organic contents were in the same range as boring 4-1 and 4-2.

Borings 4-3 and 4-9 (marsh south of Blackstone River) were accomplished to a depth of 2 feet. The materials consist of silty fine to coarse sand with a trace of gravel. Silt and organic content were relatively high for the top foot and decreased with depth for boring 4-3 (33% and 15%, and 29% and 9%, respectively). In Boring 4-9, silt and organic contents also decreased with depth (25% and 15%, and 14% and 12%, respectively).

Borings 4-5 and 4-6 (bars in the Blackstone River) were accomplished to depths of 2 feet. The material encountered consists of silty fine to coarse sand with a trace of gravel. Silt and organic contents were moderate to high. Silt content decreased or remained uniform with depth. Organic content increased or remained constant with depth. Boring 4-8 (marsh north of Blackstone River) was accomplished to a depth of 2 feet. The material consisted of gravelly, silty coarse to fine sand. Silt and organic contents were moderate and remained constant with depth (22% and 17%, respectively).

A wide range of depositional water velocities may be inferred in this area. The sands deposited in the channel and on the north side of the Blackstone River appear to be coarser than the material deposited closer to the dam. Organic and silt contents were moderately

high and relatively uniformly distributed decreasing slightly with depth.

The results of the test borings indicate the following generalized subsurface stratification starting from the ground surface:

- (a) A discontinuous layer of silty fine to coarse sand with some organics up to 2 feet in thickness.
- (b) A discontinuous layer of silty gravelly coarse to fine sand with some organics up to 2 feet in thickness.

Refusal was on hard bottom or gravel. Water levels in the boreholes were river levels.

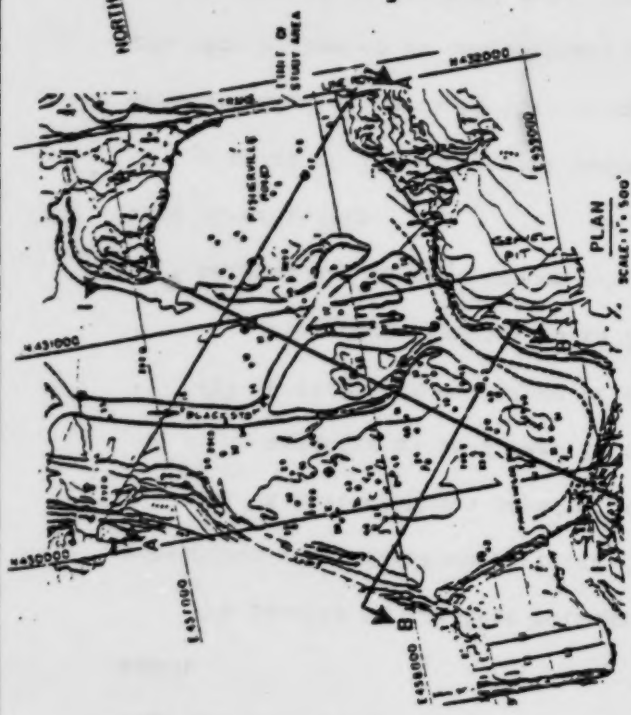
A total of 32 probes were accomplished within the study area. The probes indicated up to 10 feet or more of soft mud. The probes indicated the hard bottom to be considerably deeper in the area closer to the dam than indicated by the hand auger borings, consequently, volume of sediments are based on thicknesses as determined by the probes.

The sediments consisted of soft silt as well as sandy, gravelly and clayey layers.

3. Chemical Test Results

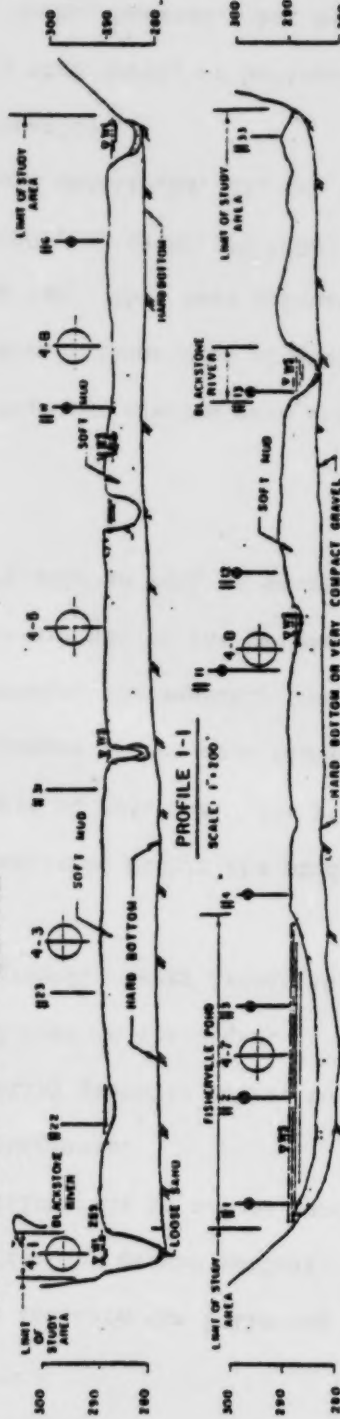
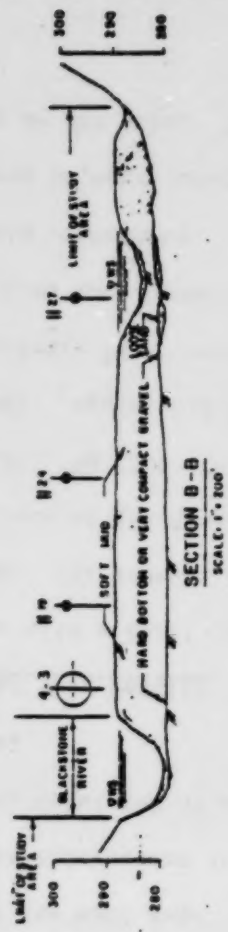
At this site a total of fourteen samples were analyzed from nine different borings. The average concentrations were slightly lower than those found upstream of the Singing Dam. They were calculated as (mg/kg): Al (13,300), As (28), Cd (30), Cr (400), Cu (900), Pb (800), Ni (70), Zn (670), Fe (42,800). Again, all those metals (As, Cd, Cr, Cu, Pb, Zn) occurred at relatively high concentrations.

Correlations of concentrations with depth, or horizontal location are not detectable whatsoever. It seems, however, that Boring 4-7 represents an area of metal content which is lower than at the other sample locations at the site. There the Quinsigamond River seems to



NOTE:

SEE FIG. III-1 FOR GENERAL NOTES AND LEGEND.



SITE NO. 4 - FISHERVILLE DAM
PLAN AND PROFILE
BLACKSTONE RIVER SEDIMENT STUDY
FIG. NO. II-4

GENERALIZED SUBSURFACE PROFILE & SECTIONS

TABLE II-4 : BULK SEDIMENT ANALYSIS

SITE 4 - FISHERVILLE DAM

SAMPLE PARAMETERS	CHRPC 208 Study	4-1-1 Channel	4-2-1 Channel	4-3-1 Bar	4-3-2	4-4-1 Channel	4-5-1	4-5-2	4-6-1 Bar	4-6-2	4-7-1 H/d Pond	4-8-1 Bar	4-8-2	4-9-1 Bar	4-9-2
Aluminum mg/kg															
Cadmium mg/kg	<u>37</u>	<u>24</u>	<u>12</u>	<u>17</u>	<u>22</u>	<u>48</u>	<u>24</u>	<u>27</u>	<u>16</u>	<u>43</u>	<u>6.4</u>	<u>37</u>	<u>70</u>	<u>26</u>	<u>34</u>
Chromium mg/kg	240	175	138	174	271	390	489	313	341	610	85	850	792	535	402
Copper mg/kg	<u>540</u>	<u>960</u>	<u>866</u>	<u>338</u>	<u>473</u>	<u>1300</u>	<u>789</u>	<u>1044</u>	<u>478</u>	<u>2133</u>	<u>138</u>	<u>810</u>	<u>1582</u>	<u>515</u>	<u>1371</u>
Iron mg/kg															
Lead mg/kg	<u>340</u>	<u>861</u>	<u>618</u>	<u>463</u>	<u>462</u>	<u>931</u>	<u>694</u>	<u>1040</u>	<u>624</u>	<u>1727</u>	<u>188</u>	<u>1074</u>	<u>1398</u>	<u>822</u>	<u>539</u>
Nickel mg/kg	71	51	50	46	56	104	71	69	57	93	34	95	149	75	72
Zinc mg/kg	570	663	488	289	452	1300	434	636	312	1422	275	518	1390	465	695
Arsenic mg/kg	2	17	18	12	16	54	28	34	28	59	27	35	39	17	17
TVS %	11.0	13.2	7.3	29.0	9.0	14.8	12.4	14.0	15.6	25.0	5.0	18.5	16.8	13.5	11.4
Gravel %		4	4	3	5	8	6	3	7	10	50	20	20	15	7
Sand %		78	84	64	80	79	51	64	67	65	43	55	60	60	78
Silt %		18	12	33	15	13	43	33	26	25	7	25	20	25	15
Distance from Bridge (Dom) [ft.]	1400	175'	500'	800'	800'	1300'	1900'	1900'	1400'	1400'	2200'	1700'	1700'	600'	600'
Depth of Sample [ft.]	1.5	1	1	1	2	1	1	2	1	2	1	1	2	1	2

govern the sediment regime. It is also interesting to note that in that area a gravel content of 50% was encountered, while throughout the rest of Site No. 4 predominantly fine grained sediments (sand, silt) were found.

The organic content of all the analyzed samples ranged between 5% and 29%, lower than those in samples from Singing Dam, but still characteristic for "pond" conditions. As before, a uniformity of metal contents seems to be a reasonable assumption in light of the limited amount of data. Table II-4 contains the results of the bulk sediment analysis.

4. Quantification of Materials

An estimate of volume of sediments with the study area was made encompassing deposits just north and south of the river channel, the bars and river and bond bottom. Area and volume are given below:

Area	83 acres
Volume	780,000 CY

F. SITE NO. 5 - NORTHBRIDGE MILL DAM

1. Description of Topography

Northbridge Mill Dam consisted of an approximately 7 foot high granite block structure with a 40 foot wide spillway. The dam was removed in the late 1960's.

The riverbed is approximately 80 to 125 feet wide upstream of the dam. An extensive plain extends upstream from the dam and its elevation is several feet higher than the river. Some erosion has occurred along the river banks.

During periods of normal flooding, portions of the plain upstream will be inundated for short periods. Fine grained sediment buildup

should be relatively slow at present. Past sediment buildup seems to be substantial. At present the higher water velocities resulting from flooding may tend to scour the riverbed.

Very little vegetative cover is present within the flood plain area at this site. This may be due to a high concentration of heavy metals, low pH, lack of fertilizer and lime, and its elevated position above groundwater or a combination of the above. Only two plant species could be identified at this site. Plan and profiles are presented in Figure II-5.

2. Geotechnical Investigations

A total of six hand auger borings were taken at Site No. 5. Two borings were located in the riverbed (5-2 and 5-6) and the remaining four (4) borings were taken on land.

Borings 5-1 (on land adjacent to the dam) was accomplished to a depth of four (4) feet. The material consists of a top 2 feet of silty gravelly coarse to fine sand, then 1 foot of silty fine to coarse sand, and 1 foot of gravelly coarse to fine sand with a trace of gravel. Silt and organic content were quite high at the top and decreased with depth (19% to 8% and 42% to 10%, respectively). Organic content was also quite low from 2 to 3 feet depth. Organic content exceeded the silt content for the top 2 feet.

Boring 5-2 (at the edge of river bank adjacent to the dam) was accomplished to a depth of 3 feet. The material consisted of silty gravelly fine to coarse sand. Organic content was low and decreased with depth (9%, 4% and 3%, respectively). Silt content remained constant with depth (20%⁺).

Boring 5-3 (on-land mid-distance from the dam) was accomplished

to a depth of 6 feet. The material consists of gravelly, silty coarse to fine sand. Organic content was relatively high for the top 4 feet (40%±) then decreased with depth to 12%. Silt content was relatively uniform with depth, 6% to 11%. Organic content exceeded the silt content by a substantial amount.

Boring 5-4 (in riverbed mid-distance from the dam) was accomplished to a depth of 1 foot. The material encountered consisted of fine to coarse sand with a trace of silt and gravel. Organic and silt contents were very low (2% and 7%, respectively).

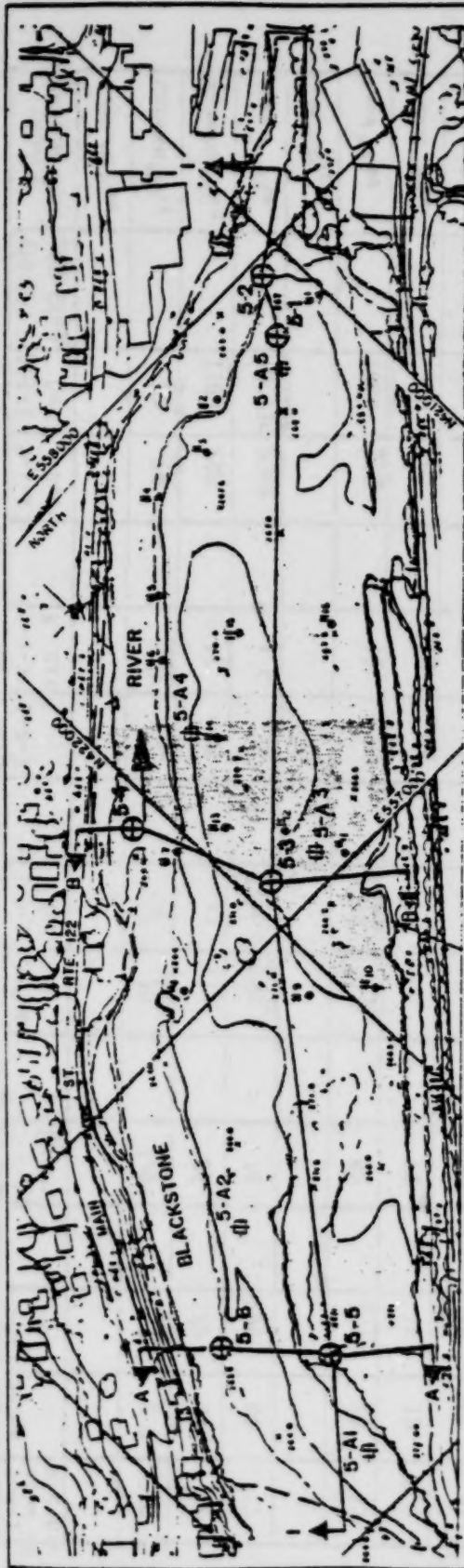
Boring 5-5 (on land furthest from the dam) was accomplished to a depth of 4 feet. The material consists of silty, gravelly fine to coarse sand. Silt content varied erratically with depth (from 7% to 37%). Organic content was relatively low for the entire depth, 2% to 8%.

Boring 5-6 (in riverbed furthest from dam) was accomplished to a depth of 1 foot. The material consists of fine to coarse sand with a trace of silt and gravel. Silt and organic content was low (7% and 4%, respectively). Refusal for all borings was on gravel or hard bottom.

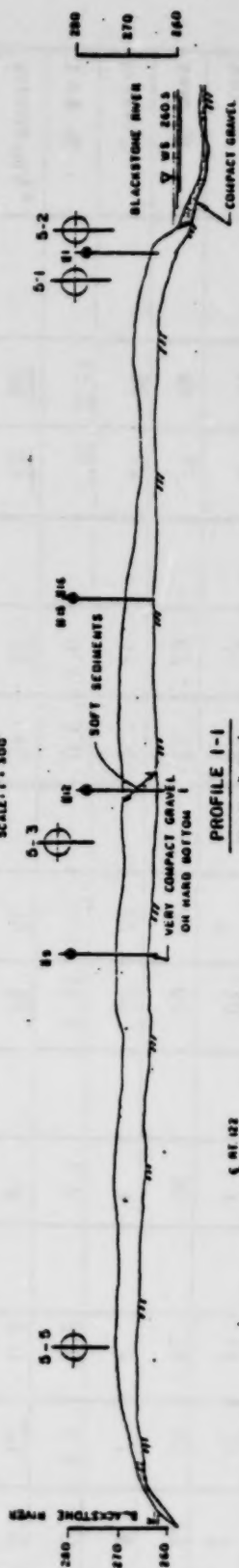
Generally silt contents were highest for those borings closest to the dam (5-1 and 5-2). Organic contents were highest in the land borings compared to those taken in the riverbed. The presence of gravel appears to be concentrated in the land areas versus riverbed sediments.

The results of the test borings indicate the following generalized subsurface stratification starting from the ground surface:

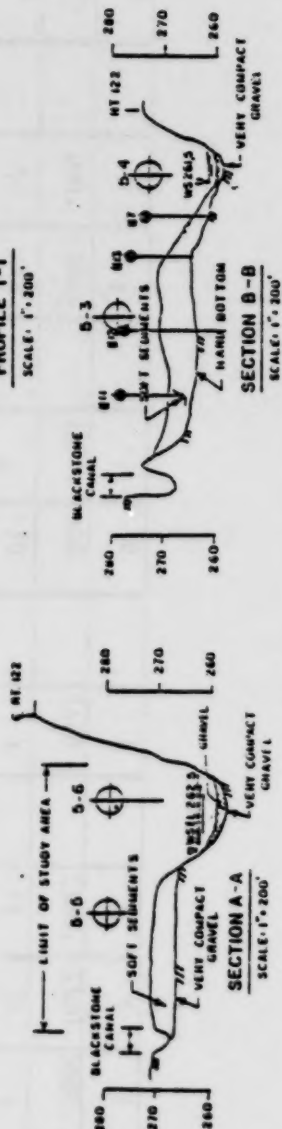
- (a) A discontinuous layer of gravelly, silty coarse to fine sand with some organics up to 6 feet in thickness (land areas).
- (b) A discontinuous layer of silty fine to coarse sand with a trace of gravel and organics up to 4 feet thick in land areas



PLAN
SCALE: 1" = 300'



PROFILE I-I
SCALE: 1" = 200'



GENERALIZED SUBSURFACE PROFILE & SECTIONS
SCALE: 1" = 200'

NOTE: SEE FIG. NO. 11 FOR GENERAL NOTES AND LEGEND

SITE NO. 5- NORTHBRIDGE MILL DAM PLAN AND PROFILE BLACKSTONE RIVER SEDIMENT STUDY

FIG. NO. 11-5

TABLE II-5: BULK SEDIMENT ANALYSIS

SITE 5 - NORTH BRIDGE MILL DAM

SAMPLE PARAMETERS	CMRPC 208 Study	5-1-1' Bar	5-1-4' Bar	5-2-1' E. Riv	5-2-3	5-3-1 Bar	5-3-6	5-4-1 Aglow	5-5-1 Bar	5-5-4	5-6-1 below 1st Mid Riv.
Aluminum mg/kg											
Cadmium mg/kg		73	24	3.0	1.0	52	35	3.9	13	2.0	0.0
Chromium mg/kg		1183	298	17	18	13	271	36	179	34	12
Copper mg/kg		10,939	2364	4.5	45	4256	1604	78	299	44	17
Iron mg/kg											
Lead mg/kg		2464	560	18	16	1979	1002	52	239	28	13
Nickel mg/kg		118	81	18	23	90	60	21	36	19	9.0
Zinc mg/kg		1085	657	240	77	693	1604	344	319	158	21
Arsenic mg/kg		89	29	19	15	49	44	14	9.0	20	8.0
TVS %		42.2	10.2	9.1	3.0	32.4	12.3	2.0	8.1	6.4	4.0
Gravel %		32	17	13	4	22	30	3	7	7	4
Sand %		49	75	67	73	70	60	90	76	56	89
Silt %		19	8	20	23	8	10	7	17	37	7
Distance from Bridge (Down) [ft.]		500'	500'	500'	500'	1800'	1800'	1750	2700'	2700'	2700'
Depth of Sample [ft.]		1	4	1	3	1	6	1	1	4	1

and 1 foot thick in water areas.

Groundwater levels in the boreholes were river levels.

Sixteen probes were accomplished within the study area. Probe depths were generally in agreement with hand auger depths. The sediments consisted of firm to loose silts with occasional sandy strata.

Since this area is almost completely deficient in vegetative cover, in addition to auger borings, and probes, several topsoil samples were taken. The analysis was done by the Agricultural Extension Service in Waltham. In addition to pH, nutrients, and trace elements, the lab also performed a heavy metal analysis of available or leachate portion of these metals. The analysis indicated a highly acid soil (pH less than 5) and low nutrient content.

3. Chemical Test Results

Upstream from the Northbridge Mill Dam, a total of ten samples were analyzed. Six samples were taken from the extensive bank of sediments and four samples were taken from the bottom of the Blackstone River. The mean values for this site were as follows: Al (12,000), As (30), Cd (20), Cr (200), Cu (2,000), Fe (63,000), Pb (640), Ni (47), Zn (520). These "average" concentrations are misleading because the samples were taken from environmentally different sites; i.e., river bottom and large exposed sand bank. The coefficients of variance accordingly reach almost 200% in some instances.

An analysis of the riverbottom gives the following averages: Al (8,200), As (14), Cd (2), Cr (21), Cu (50), Fe (26,000), Pb (26), Ni (18), Zn (170). This is the lowest average of most of the metals encountered in the samples from Sites No. 1 through Site No. 5. Physical erosion and chemical purification by the river is most likely accountable for this condition. A "healthy" vegetation along the river banks upstream of the

former dam seems to support this finding.

An analysis of the sandbank revealed: Al (14,500), As (40), Cd (33), Cr (330), Cu (3,250), Fe (87,000), Pb (1,045), Ni (67), Zn (750). Metals like cadmium, chromium, lead and zinc occur within the bank at concentrations which are far higher than those measured in the river bottom. Copper, lead and zinc were found at the highest levels relative to all of the upstream sites. The absence of vegetation on the sandbank bears witness of the soil conditions.

Borings 5-1 and 5-3 showed organic contents of up to 40%. It is in those places where the highest relative maximum of all of the metals were found. Clearly, at Site No. 5 different conditions occur in the river sediments compared to those present in the sand bank. This may be environmentally significant and should be evaluated in more detail. Table II-5 contains the results of the bulk sediment analysis.

4. Quantification of Materials

An estimate of volume of sediments was made encompassing the deposits on the west bank of the river and those in the river bottom. Area and volume are given below:

Area	32.8 acres
Volume	215,000 CY

G. SITE NO. 6 - RIVERDALE MILL DAM

1. Description of Topography

Riverdale Mill Dam consists of a poured concrete overflow structure approximately 125 feet long. Flash boards were used to raise water levels behind the dam approximately 7 to 8 feet. At present, the dam has been removed with the exception of approximately two feet of either flashboards or debris.

The riverbed is approximately 80 to 150 feet wide upstream of the dam. An extensive plain opens up upstream from the dam with an elevation several feet higher than the river. The river meanders through the study area and divides at two locations to form bars in the river. Significant erosion has occurred along the river banks.

The present spillway is a constriction to the river in times of flooding. During periods of dry weather flow, the river remains within a well defined riverbed.

During periods of flooding, portions of the plain upstream of the dam will be submerged for short periods of time. Fine grained sediment buildup should be relatively slow at present. Past sediment buildup may have been substantial. At present, the higher water velocities resulting from flooding will tend to scour the riverbed.

There is little cover within the flood plain area at this site. This may be due to a high concentration of heavy metals inhibiting growth, low pH, lack of fertilizer and lime, its elevated position about groundwater, or a combination of the above. Nineteen different species of plants were identified.

Plan and profiles are presented in Figure II-6.

2. Geotechnical Investigations

A total of five test borings were taken at Site No. 6. Four borings were taken on land (6-1, 6-2, 6-4, and 6-5) and one boring in the riverbed (6-3).

Boring 6-1 (on west bank 950 feet from dam) was accomplished to a depth of 4 feet. The material consists of a top 2 feet of gravelly coarse to fine sand with a trace of silt and considerable organics, then 2 feet of silty fine to coarse sand with a trace of gravel and organics.

The organic content in the top 2 feet substantially exceeded the total silt content (32% and 24% versus 6% and 12%, respectively).

Boring 6-2 (bar in river 500 feet from dam) was also accomplished to a depth of 4 feet. The material consists of a top one foot of silty, gravelly fine to coarse sand. Organic content was moderate (16%). Then, below the top foot was 3 feet of silty gravelly fine to coarse sand. Organic contents were relatively low (3% to 6%).

Boring 6-3 (riverbed, 1100 feet from dam) was accomplished to a depth of 1 foot. The material consists of silty fine to coarse sand with a trace of gravel. Organic contents were relatively low here also.

Boring 6-4 (east bank, 1500 feet from dam) was accomplished to a depth of 5 feet. The material consists of gravelly, silty fine to coarse sand for the top 1 foot, then 4 feet of gravelly, silty coarse to fine sand. Silt content varies with depth (22% to 7%). Organic contents are relatively high for the full depth, and in some samples exceeding the silt content substantially.

Boring 6-5 (bar in river 2000 feet from dam) was accomplished to a depth of five feet. The material encountered consists of gravelly, silty fine to coarse and coarse to fine sands. The material varied erratically with depth. Silt, gravel, and organic contents were moderate to high (10% to 30% organic content) indicating wide ranges of depositional velocities.

Generally, the above coarser graded sands appear to be located furthest from the dam. Silt and organic contents were moderate to high at all locations sampled. The sample taken in the riverbed was low in silt and organic content.

The results of the test borings indicate the following generalized subsurface stratification starting from the ground surface:

- (a) A discontinuous layer of gravelly, silty coarse to fine and fine to coarse sands with moderate to high organic contents up to 5 feet in thickness (land borings).
- (b) A discontinuous layer of silty fine to coarse sand with a trace of gravel up to 1 foot in thickness with low organic content (riverbed).

Refusal in all cases was on compact gravel. Groundwater levels in the borings were river levels.

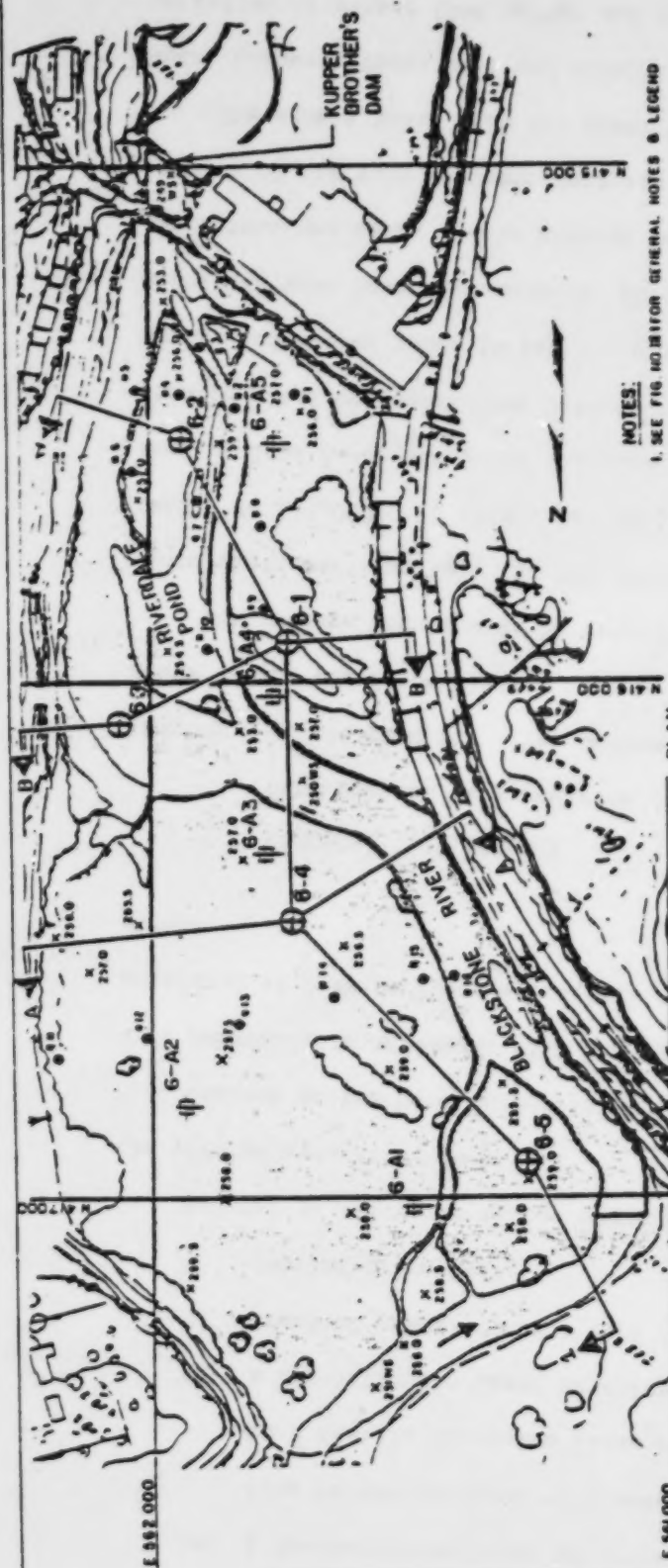
Sixteen probes were accomplished in the study area. Probe depths were generally in agreement with hand auger depths. The sediments consisted of firm to loose silts with occasional sandy and gravelly strata.

3. Chemical Test Results

Nine samples were analyzed from within the Riverdale Pond. One (Boring 6-3) was from the river bottom. The rest were taken from four spots within the flood plain.

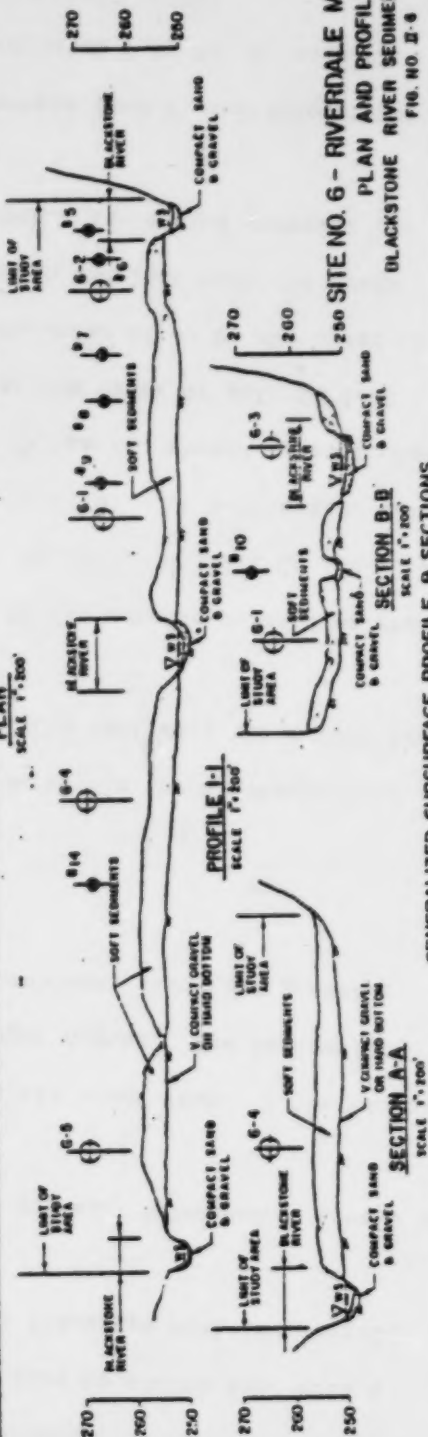
The average occurrences of metals in the samples taken from the flood plain were (mg/kg): Al (12,700), As (24), Cd (31), Cr (467), Cu (819), Fe (38,000), Pb (576), Ni (58), Zn (810). In particular, the samples from Borings 6-2 and 6-1 close to the dam showed a clear distinction in metal concentrations between the top layer of soil (1 foot depth) and deeper zones (4 feet). Differences of up to one order of magnitude were found for cadmium, chromium and lead with the lower concentrations being at the greater depth. Table II-6 contains the results of the bulk sediment analysis.

The sample taken from the river bottom (6-3-1) contained lower metal concentrations than any other sample at Site No. 6, with the exception of copper (346 mg/kg) and zinc (4650 mg/kg).



NOTES:
1. SEE FIG. NO. 10 FOR GENERAL NOTES & LEGEND

PLAN
SCALE 1" = 200'



GENERALIZED SUBSURFACE PROFILE & SECTIONS

250 SITE NO. 6 - RIVERDALE MILL DAM
PLAN AND PROFILE
BLACKSTONE RIVER SEDIMENT STUDY
FIG. NO. 2-9

TABLE II-6: BULK SEDIMENT ANALYSIS

SITE 6 - RIVERDALE MILL DAM										
SAMPLE PARAMETERS	CMRPC 208 Study	6-1-1 Bank	6-1-4	6-2-1 Bar	6-2-4	6-3-1 Mid Riv.	6-4-1	6-4-5 Bank	6-5-1 Bar	6-5-5
Aluminum mg/kg		24,000	7983		13,146	9583		15900	15300	13800
Cadmium mg/kg	65	138	4.0	50	3.9	3.9		47	54	9.0
Chromium mg/kg	1100	1879	39	458	36	16	615	418	752	1145
Copper mg/kg	1100	3264	100	1096	326	346	992	965	1188	281
Iron mg/kg		159,000	9680	52,200	12,400	9200	51300	57700	49100	11050
Lead mg/kg	1000	2176	41	550	41	22	982	627	1188	171
Nickel mg/kg	160	168	26	66	40	13	72	76	85	38
Zinc mg/kg	970	1478	180	856	622	4650	635	1493	792	281
Arsenic mg/kg	0.48	12	5.0	34	13	9	34	43	36	15
TVS %	16.0	32.3	3.4	16.0	2.6	4.5	18.3	18.5	13.9	26.6
Gravel %		25	7	18	5	7	10	25	12	24
Sand %		69	75	68	85	75	68	68	63	53
Silt %		6	18	14	10	18	22	7	25	23
Distance from Bridge (Dom) [ft.]	100	950	950	500	500	1100	1100	1500	2000	2000
Depth of Sample [ft.]	.5	1	4	1	4	1	1	5	1	5

The coefficients of variance were between 15% and 75% for the top of the flood plains and between 45% and 125% for the bottom.

Again, some correlation seems to exist at Site No. 6 between organic content and metal concentrations, although less marked than at Site No. 3. Additional data would be required to substantiate this apparent trend.

In addition to auger borings, several topsoil samples were taken on the land portions of the site, since this area is almost completely void of vegetative cover. The analysis was done by the Agricultural Extension Service as described previously for Site No. 5: The analysis indicated a highly acid soil, i.e., pH less than 5 and a low nutrient content.

4. Quantification of Materials

An estimate of volume of sediments was made encompassing deposits east and west of the river channel, and also those within the river. The area and volume are given below:

Study Area	35.5 acres
Volume	225,000 CY

H. SITE NO. 7 - RICE CITY POND

1. Description of Topography

Rice City Pond Dam consists of two control structures. The main spillway is less than 50 feet long and about 6 feet high. An emergency spillway is about 5 feet high and 75 feet long. Wood flash boards may have been used to raise water levels in the past. These are relatively shallow, i.e., 5 feet or less. A gate control structure located adjacent to the emergency spillway served as part of the Blackstone Canal System.

The study area at Site No. 7 is almost entirely within the reservoir impounded by the dam and, except for the extensive islands on the north end of the reservoir, it is almost all below water. As mentioned earlier the depths of water are generally five feet or less and consequently were not suitable for performing a D.R.E. survey.

The reservoir area immediately upstream of the dam is relatively wide (800 feet) and long (4000 feet) and is bounded by moderately sloping hills along its length. Portions of the Blackstone Canal embankment are exposed along the west shoreline. A relatively wide potential flood plain extends along the Blackstone River starting about 4000 feet upstream of the dam. During the dry season some of the sediments may be exposed.

During periods of normal wet weather, portions of the plain upstream of Rice City Pond are water covered for short periods. The moderately steep hills along the length of the Pond prevent significant flooding in these directions. During periods of extended dry weather, sizeable areas of bottom sediments (80%) become exposed and water flow becomes channelized in and adjacent to the Blackstone Canal.

The large extent of this "reservoir" should serve to contain most sediments that have entered from the Blackstone River.

Vegetative cover is present along the banks and along the exposed Blackstone Canal embankment in the reservoir. Grasses and/or trees are prevalent in the above area. Reeds and sedge grass are abundant in the islands in the north end of the reservoir. During extended dry periods, such as the summer of 1980, vegetative growth is quite lush on the exposed sediments, including reeds, sedge grasses, lillies, and weeds. A total of 23 different plant species were identified at this site. Plan and profiles are presented in Figure II-7.

2. Geotechnical Investigations

A total of six hand auger borings were taken at the site. Two borings (7-1 and 7-2) were taken on land and four borings (7-3 to 7-6) were taken in water covered areas.

Boring 7-1 (bar 3700 feet upstream of dam) was accomplished to a depth of 5 feet. The material consists of top 2 feet of gravelly, silty coarse to fine sand. Organic and silt contents were moderate (about 17% to 22%), then 3 feet of silty fine to coarse sand with a trace of gravel. Organic content decreases with depth (10% to 2%). Silt content also decreases with depth (27% to 7%).

Boring 7-2 (bar 2800 feet upstream of dam) was accomplished to a depth of 4 feet. The material encountered consists of silty fine to coarse sand with a trace of gravel for the full depth. Organic content was moderate to low and decreased with depth (from 12% to 6%). Silt content was moderate to low and decreased with depth (from 12% to 6%). content was moderate (10% to 20%) and was erratic with depth.

Borings 7-3 through 7-6 were taken below the water surface at 2000 feet, 1500 feet, and 400 feet from the dam, respectively. These borings hit refusal at 1 foot depth. The two borings furthest from the dam encountered silty coarse to fine sand with a trace of gravel. Organic content was moderate to high (12% to 34%) and erratic in location. Silt content was moderate (7% to 25%) and also erratic in location.

In the reservoir, generally finer sands and gravels are found closest to the dam, although silt and organic content showed no trend. Within the island area, the coarser material appears to overlie the finer soil. The finer soil appears to be closer to the dam. Organic content appears to decrease with depth, although silt content does not appear to decrease with depth.

The results of ten test borings indicate the following generalized subsurface profile starting from the ground surface:

- (a) A discontinuous layer of gravelly, silty coarse to fine sands with moderate organic content up to 2 feet in thickness (in bar areas).
- (b) A discontinuous layer of silty fine to coarse sand with a trace of gravel with moderate to low organic content up to 4 feet in thickness (in bar areas).
- (c) A discontinuous layer of silty fine to coarse and coarse to fine sand with moderate to high organic content. Refusal was on hard bottom or compact gravel.

Water levels in the boreholes were equal to water levels in the reservoir.

A total of 34 probes were accomplished within the reservoir at the time when the majority of it was exposed. The probes indicated up to 5 feet of soft mud, which consisted of sandy, clayey organic silt variations in sand.

3. Chemical Test Results

In Rice City Pond eight samples were taken from a rather widespread area. Four of those samples stemmed from a shallow layer (1 foot depth) of river sediments. The remaining four samples were taken from two locations in the flood plains (sand bar) far upstream of the impoundment (2800 to 3700 feet). Rice City Pond seems to contain the highest average total concentrations of metals of all the sites along Blackstone River. There were considerable deviations from the "mean"

levels, however. Table II-7 contains the results of the bulk sediment analysis.

A clear correlation seems to exist between organic content (between 2.2% and 34%) and metal concentrations. Both samples taken from lower depth of the flood plain (7-1 and 7-2) contained less amounts of organics and metals than the two surface layer samples and all the other four samples taken from within the ponded area.

The two samples taken from the bottom sediments of the Blackstone Canal (7-3 and 7-5) showed nearly matching metal concentrations.

Sample 7-6 taken from an area close to the impoundment contained by far the highest concentrations of the whole Site No. 7. The levels found were: Al (32,000), As (130), Cd (411), Cr (2,900), Cu (4,600), Fe (72,100), Pb (3,500), Ni (1,200), Zn (13,200). Excessive concentrations at this location are noteworthy.

The area right next to the former Rice City Pond Dam, which may have functioned as a locally confined settling basin, seems to have high levels of metals, as compared to the other locations at this site. Similarly, although to a lesser degree, the area at the far upstream end of the pond (7-1) seems to contain relatively high amounts of metals.

4. Quantification of Materials

An estimate of volume of sediments was made encompassing deposits within bars, bottom sediments with the reservoir, and those in channelized river areas. Area and volume are given below:

Study Area	90 acres
Volume	525,000 CY

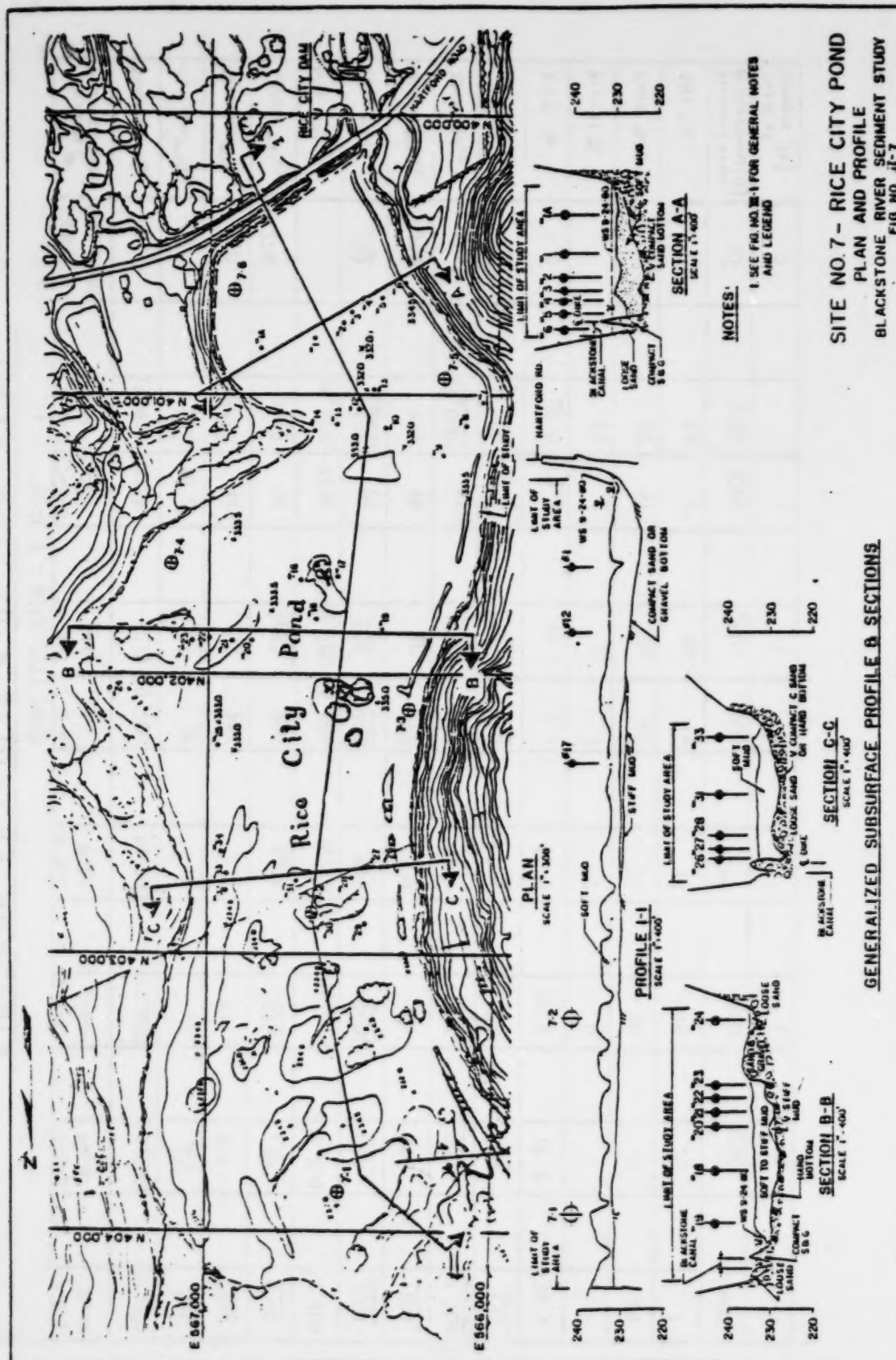


TABLE II-7: BULK SEDIMENT ANALYSIS

SITE 7 - RICE CITY POND										
SAMPLE PARAMETERS	CMRPC 208 Study	7-1-1 Bar	7-1-5 Bar	7-2-1 Bar	7-2-4	7-3-1 Pond	7-4-1 Pond	7-5-1 Pond	7-6-1 Pond	
Aluminum mg/kg		19,900	7239	1279	10,100	14,900	19,600	15,000	32,000	
Cadmium mg/kg	17	83	0.0	43	19	91	31	31	411	
Chromium mg/kg	210	1393	34	433	247	775	915	409	2900	
Copper mg/kg	220	1592	64	1083	296	1094	995	748	4600	
Iron mg/kg		58,500	7636	28,700	16,600	36,900	48,300	34,200	72,100	
Lead mg/kg	190	1492	29	561	454	895	1094	838	3500	
Nickel mg/kg	110	119	18	18	30	239	86	142	1200	
Zinc mg/kg	370	11,000	51	1083	681	1700	647	1000	13,200	
Arsenic mg/kg		38	7.0	21	18	25	41	30	130	
TVS %	1.9	22.8	2.2	11.7	6.7	19.0	20.2	12.3	34.3	
Gravel %		15	2	5	3	12	5	3	7	
Sand %		67	91	75	80	72	80	72	86	
Silt %		18	7	20	17	16	15	25	7	
Distance from Bridge (Dam) [ft.]	50'	3700	3700	2000	2000	2050	1500	1200	400	
Depth of Sample [ft.]	2	1	5	1	4	1	1	1	1	

I. SITE NO. 8 - LACKEY POND

1. Description of Topography

Lackey Dam consists of an earthfill section and a granite block and timber weir spillway section. Dam height is approximately 15 feet. Spillway height is about 10 feet. Reservoir depths are up to 12 feet deep. This dam is located on the Mumford River which drains into the Blackstone River below Rice City Pond. Plan and profiles are presented in Figure II-8.

The study area is entirely within the reservoir impounded by the dam. A hydrographic survey was taken within the reservoir area. The reservoir is quite irregular in shape and is about 5,000 feet long and 200 by 1200 feet wide. The reservoir area near the dam is bounded by hilly terrain.

Slopes along the reservoir near the dam are gentle to moderate. Two marshy areas were noted adjacent to the shore. A marshy area is located about 1800 feet from the dam (approximately 500 x 500 feet square). Another marshy area is located at uppermost end of the reservoir.

During periods of normal flooding, the marshy areas may be temporarily water covered. The moderate to gentle slopes along the reservoir near the dam should not result in significant flooding in these directions. The large extent of this reservoir should serve to contain most sediments entering from the Mumford River.

Vegetative cover is present along the banks and in the marsh area. Grasses and/or trees are prevalent along the shoreline. Reeds and sedge grass are abundant in the marshes. A total of 33 plant species were found at this site.

2. Geotechnical Investigation

A total of 6 test borings were taken at the site. All borings

were taken below the water surface at various distances from the dam.

Boring 8-1 (2000 feet upstream of dam on east bank) was accomplished to a depth of 1 foot. The material consists of silty, gravelly fine to coarse sand. Silt content was relatively high (28%) and organic content low (4%).

Boring 8-2 (2000 feet upstream of dam on west bank) was accomplished to a depth of 1 foot. The material encountered consists of gravelly coarse to fine sand with a trace of silt. Organic content was moderate and considerably higher than silt content (11% and 3%, respectively).

Boring 8-3 (2400 feet upstream of dam on east bank) was accomplished to a depth of 1 foot. The material encountered consists of similar soils as found in Boring 8-2. However, silt content was slightly higher and organic content lower (7% and 4%, respectively). Boring 8-4 (1100 feet upstream of dam on the east bank) was accomplished to a depth of 1 foot. The material encountered consists of gravelly, silty coarse to fine sand. Organic and silt content were similar to Boring 8-3.

Boring 8-5 (4300 feet upstream of dam on the west bank) was accomplished to a depth of 2 feet. The material encountered consists of fine to coarse sand with a trace of silt and gravel. Organic contents were low (3% to 9%).

Boring 8-6 (4400 feet upstream of dam on east bank) was accomplished to a depth of 1 foot. The materials consists of gravelly coarse to fine sand with a trace of silt. Organic content was high (26%). All borings hit refusal on gravel or hard bottom.

Generally, the depths of sediments were shallow throughout the length of the reservoir (1 to 2 feet). The hydrographic survey indicated water depths up to 9 feet. It also appeared to confirm the shallow

thickness of sediments in that there was little or no penetration into these materials. Organic and silt contents were low, except for high silt content in Boring 8-1 and high organic content in Boring 8-6. The majority of the sediment material consists of sands.

The results of the test boring program indicate the following generalized subsurface profile starting from the ground surface:

A continuous layer of gravelly silty fine to coarse sand and coarse to fine sands up to 2 feet in thickness with low organic content.

Refusal was on hard bottom or compact gravel. Ground water levels were equal to the reservoir.

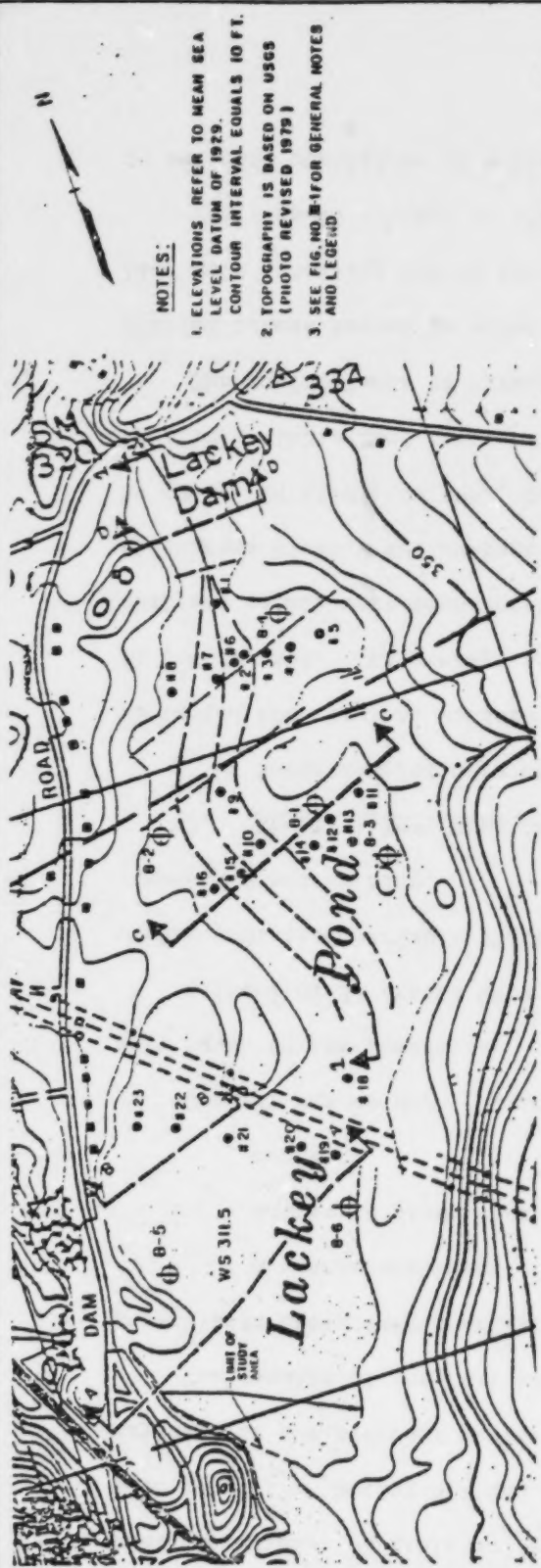
A total of 33 probes were accomplished within the study area. The probes indicated variable thickness of soft sediments, including sandy layers and sticky clay.

3. Chemical Test Results

Seven samples were chemically analyzed. Six of those samples reflected the chemical conditions of the top layer of the pond sediments (1 foot depth). The average total concentrations of nearly all of the analyzed metals were considerably lower than at all sites along the Blackstone River. The average values expressed in mg/kg were: Al (12,600), As (8.4), Cd (1.0), Cr (96), Cu (56), Fe (8,800), Pb (41), Ni (14) Zn (230). Table II-8 contains the results of the bulk sediment analysis.

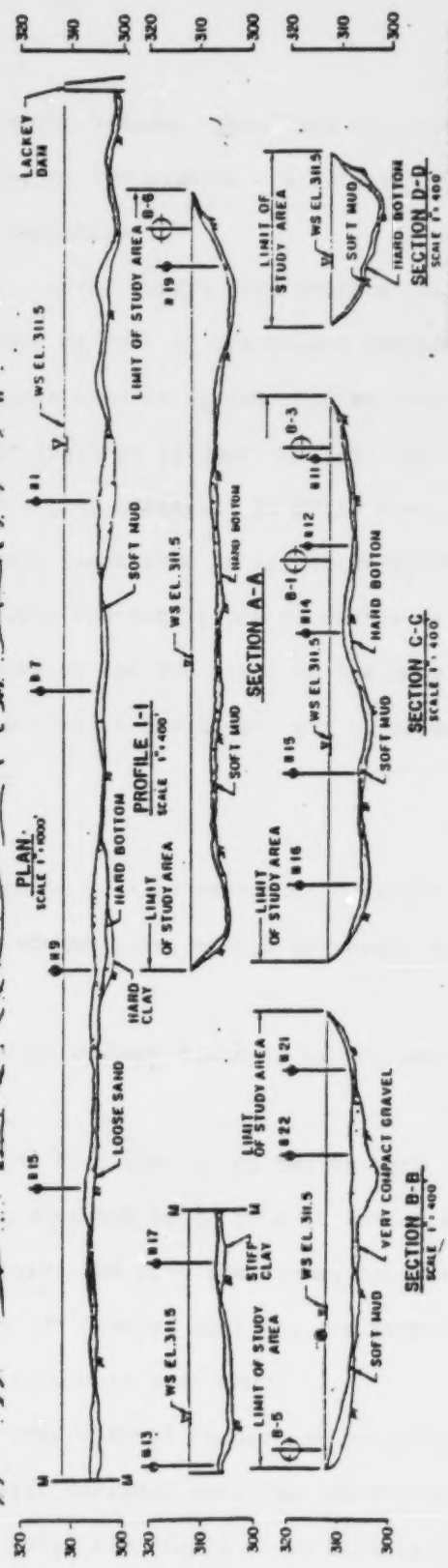
The coefficients of variance of most of the metals reached 100%. No spatial trends seemed to exist. Heavy metals like cadmium, arsenic and lead were generally low in concentration.

The organic content of most of the samples is very low and similar to sediment conditions in a flowing stream. There was one sample,



NOTES:

1. ELEVATIONS REFER TO MEAN SEA LEVEL DATUM OF 1929.
CONTOUR INTERVAL EQUALS 10 FT.
2. TOPOGRAPHY IS BASED ON USGS (PHOTO REVISED 1979)
3. SEE FIG. NO. 8 FOR GENERAL NOTES AND LEGEND.



SITE NO. 8 - LACKEY POND
PLAN AND PROFILE
BLACKSTONE RIVER SEDIMENT STUDY
FIG. NO. 8-B

GENERALIZED SUBSURFACE PROFILE & SECTIONS

TABLE II-8: BULK SEDIMENT ANALYSIS

SITE 8 - LACKEY POND

SAMPLE PARAMETERS	CMRPC 208 Study	Pond 8-1-1	Pond 8-2-1	Pond 8-3-1	Pond 8-4-1	Pond 8-5-1	Pond 8-5-2	Pond 8-6-1
Aluminum mg/kg		12,000	5500	14,900	24,300	10,800	10,500	10,500
Cadmium mg/kg	20	0.0	1.0	1.0	1.0	1.0	0.0	3.0
Chromium mg/kg	3300	22	216	29	48	37	96	311
Copper mg/kg	180	34	80	20	21	20	184	38
Iron mg/kg		12,500	6590	10,900	10,500	6600	5420	9130
Lead mg/kg	270	43	44	17	20	13	22	130
Nickel mg/kg	20	14	5.9	11	14	13	11	31
Zinc mg/kg	5300	439	147	93	648	71	120	110
Arsenic mg/kg		7.0	14	6.0	12	6.0	7.0	7.0
TVS %	33.0	4.3	11.4	4.1	6.1	2.7	8.8	26.2
Gravel %		10	30	21	18	2	2	23
Sand %		62	67	72	70	91	91	71
Silt %		28	3	7	12	7	7	6
Distance from Bridge (Dam) [ft.]	100	2000	2000	2400	1109	4300	4300	4400
Depth of Sample [ft.]	8	1	1	1	1	1	2	1

however, which contained volatile solids of 26%. It is the same sample (8-6) which contained relative maximum concentrations for chromium (311), lead (130) and nickel (31).

It should be noted that a sample taken earlier from the pond close to the spillway ("Benthic Analysis," Central Massachusetts Regional Planning Commission, February 27, 1978) contained far higher metal concentrations than most of the samples analyzed for this study. While the latter were taken from a very shallow depth, the earlier sample stemmed from a depth of eight feet. This fact may indicate that higher metal concentrations occur in deeper historical layers of sediments.

4. Quantification of Materials

An estimate of volume of sediments was made encompassing deposits with the pond. The area and volume are given below:

Study area	105 acres
Volume	170,000 CY

J. Extraction Procedure -(EP) Toxicity Test

As part of the hazardous waste and consolidated permit regulations published in the Federal Register, May 18, 1980, the Environmental Protection Agency established the EP-toxicity test as a means of determining whether or not a waste is hazardous (Federal Register, Vol. 45, No. 98, S. 261.24). "A solid waste exhibits the characteristic of EP Toxicity if, using the test methods described in Appendix II or equivalent method approved by the Administrator ..., the extract from a representative sample of the waste contains any of the contaminants listed in Table 1 at a concentration equal to or greater than the respective value given in that Table." The portion of Table 1, "Maximum concentration of contaminants for characteristic of EP Toxicity, regarding heavy metals is presented as follows:

<u>EPA Hazardous Waste Number</u>	<u>Contaminant</u>	<u>Maximum Concentration (mg/l)</u>
D004	Arsenic	5.0
D005	Barium	100.00
D006	Cadmium	1.0
D007	Chromium	5.0
D008	Lead	5.0
D009	Mercury	0.2
D010	Selenium	1.0
D011	Silver	5.0

Additional core samples were collected at Sites 5 and 6, as these sites were considered representative of "worst-case" conditions compared to other sites based on the levels of total metals. Sampling stations were located as close as possible to core stations from which metal samples were taken. Samples were collected by DEQE project staff and delivered to the Lawrence Experiment Station for analysis. Samples were analyzed at LES according to the test procedures outlined in the Federal Register. Based on the results of this test, presented in Table II-9, the in-place sediments in the Blackstone River do not constitute a hazardous waste as provided in the test definition. No further testing using this procedure was considered necessary at these or other sites.

K. Sediment Bioassay - Chronic Toxicity

In order to determine the effects of sediment on aquatic organisms, sediment bioassays were performed by the EPA Region I Regional Environmental laboratory. Sediment samples were collected from sites 3, 4, 5, and 7. Daphnia Magna and Fathead minnows were used as test organisms. A control

TABLE II-9
Results of EP Toxicity Test - Blackstone River Sediments

Contaminant	Maximum Concentration (mg/l)	Test Results - (mg/l)					
		Rockdale - Site 5		Riverdale - Site 6			
		5-1	5-2	5-3	6-1	6-2	6-3
Arsenic	5.0	0.000	0.000	0.000	0.000	0.000	0.000
Cadmium	1.0	0.03	0.10	0.04	0.07	0.00	0.08
Chromium	5.0	0.00	0.00	0.00	0.00	0.00	0.00
Lead	5.0	0.00	0.00	0.02	0.01	0.00	0.01

site was selected outside the Blackstone River basin. A clean source water was used in the laboratory. Test organisms were observed over a ten-day period.

The sediment bioassay apparatus utilized was similar to that described by Prater and Anderson (1977) with modifications added by the NERL staff. Continuous flow through the all-glass system was supplied by pumping water via an airlift (made of 4mm ID glass tubing) from a 4-l jar through the test chamber and into another 4-l jar by means of an intermittent siphon. Water was constantly returned by a siphon set up between the two 4-l jars (made of 10mm ID tubing). The flow rate was sufficient to maintain DO levels of 7 mg/l, but did not disturb the surface layer of the test sediments.

Prior to test animal exposure, the bioassay chambers were filled with the various test sediments to a level of 50mm. Surface water collected from a tributary of the Shawsheen River, Bedford, was added to each chamber after mixing and aeration and the entire system was left idle for 24 hours to promote settling. The surface water was initially tested for daphnid survivability and DO, pH, and temperature. These three chemical parameters were monitored daily throughout the test.

Tests were conducted on sediments from the four previously mentioned stations, plus a control sediment collected from the same Shawsheen River site as the surface water. Each sediment was run in three replicates using 10 fathead minnows and 10 daphnias per chamber for a total of 15 separate bioassays. To avoid predation of the Daphnia by the minnows, cages were constructed of a 90mm diameter petri dish as the base and 0.5mm mesh NITEX screen as the walls. The screen was attached to the base by silicon rubber cement. The cages were placed directly on the test sediments in each chamber.

Test animals of a similar size were added to the chambers in a random two-at-a-time fashion until the correct number was reached and were checked every 24 hours for signs of stress or mortality. During the 10 day test no feeding was performed.

The actual test began on 11 December 1980, after the 24 hour settling period was completed. The entire bioassay was conducted in an environmental room where the temperature was maintained at 20°C ($\pm 1^\circ\text{C}$) and the photoperiod adjusted to 14 hours of daylight.

In the first 48 hours of testing no direct signs of stress were observed in either test species; however, between 48 and 96 hours, the D. magna experienced a total mortality (0% survival) in chambers series D and E (see Table II-10). Death was defined as no apparent locomotion. At the end of the 10 day period all the fathead minnows survived since the losses incurred were directly attributable to impingement in the intermittent siphon tube. Daphnia survivability in chamber series A, B, and C was 100%. The total survivability values were 98%, 95%, and 97% in series A, B, and C, respectively, and 48% in series D and E.

These results indicate that bottom sediments from Rice City Pond and Sutton Street are toxic to daphnids within a 96 hours period. Although no toxic effects to the fathead minnows were observed, they did appear to be stressed in chamber series A, D, and E by exhibiting fecal trailings and curved spines.

The U.S. EPA EMSL/ORD, Las Vegas, has agreed to analyze the fathead minnow tissue for cadmium, copper, chromium, zinc, lead, arsenic and nickel and also analyze the sediments for the same metals. The results of these analyses will be included in a follow-up report and will greatly aid in defining the effects of these Blackstone River sediments on aquatic life.

Table II-10 Survivability of fathead minnows (Pimephales promelas) and water fleas (Daphnia magna) subjected to Blackstone River, Massachusetts, bottom sediments after a 10-day exposure period.

Series Station	A Singing Dam Sutton				B Fisherville Dam Grafton				C Control				D Rice City Pond Uxbridge				E Sutton Street Northbridge			
(n)	1	2	3	(%S)	1	2	3	(%S)	1	2	3	(%S)	1	2	3	(%S)	1	2	3	(%S)
Fathead Minnows <u>Pimephiles promelas</u>)	10	10	9	(97)	7	10	10	(90)	9	9	10	(93)	10	10	9	(97)	10	9	10	(97)
Daphnids <u>(Daphnia magna)</u>	10	10	10	(100)	10	10	10	(100)	10	10	10	(100)	0	0	0	(0)	0	0	0	(0)
Total Survivability	20	20	19	(98)	17	20	20	(95)	19	19	20	(97)	10	10	9	(48)	10	9	10	(48)

(n) = replicates
(%S) = percent survivability

L. Fisheries Survey - Fish Tissue Analysis

A fisheries survey of the Blackstone River was conducted in May, 1981 in a cooperative effort by DEQE project staff and personnel of the Division of Fisheries and Wildlife. The purposes of the survey were to assess the composition and condition of the fisheries in the Blackstone River and to collect fish samples for heavy metal analysis in the flesh.

Ten stations were selected for samples, as follows:

<u>Station Number</u>	<u>Stream Name</u>	<u>Location</u>	<u>Town</u>
1	Kettle Brook	James St.	Leicester
2	Kettle Brook (Outlet Leesville Pd)	USGS Gauge	Worcester
3	Middle River	St. John's Cemetery	Worcester
4	Blackstone River	Cross Street	Millbury
5	Blackstone River	Pleasant Street	Grafton
6	Quinsigamond River	Pleasant Street	Grafton
7	Blackstone River	Sutton Street	Northbridge
8	Rice City Pond	Hartford Road	Uxbridge
8A	Below Dam, Rice City Pd Rice City Pond	Hartford Road	Uxbridge
9	Blackstone River	Route 122	Uxbridge
10	Blackstone River	Route 122	Millville/ Blackstone

Fish were collected using electroshock techniques at all stations except 4 and 8A. Gill nets were used at these two locations. Quantitative samples were taken at (Numbers of fish, length and weight) all stations except 4, 8, 8A, and 10. Quantitative samples (kinds of fish) were taken at these stations.

Fish tissue samples were prepared by DEQE project staff, labeled, and delivered to the Lawrence Experimental Station. The tissue samples will

be analyzed for mercury, arsenic, copper, lead, nickel, zinc, cadmium and chromium. Depending on the number of fish available, size of fish and sample size required for analysis, three to eight fish were used to comprise a sample. Samples were prepared for each species collected (provided a sufficient number of fish of each species were collected).

Table II-11 provides a qualitative listing of the species of fish collected at each sampling station. Quantitative survey data and fish tissue analyses will be provided as soon as they become available.

M. Water Quality Analysis for Heavy Metals - Blackstone River

In conjunction with an intensive water quality survey of the Blackstone River conducted by the Division of Water Pollution Control and DEQE staff, samples were collected for analysis of heavy metals. Analysis included aluminum, arsenic, cadmium, chromium (total), copper, iron, lead, nickel and zinc. Nine stations encompassing the sediment sampling sites and all but one fisheries sampling site were included in the metals sampling program. The stations and the metals data are presented in Table II-12.

Table II-12 Heavy Metals - Water Column - Blackstone River, 1980 Survey

Parameter	BS01	BS08	BS09B	BS10	BS12	BS13	BS14	BS15	BS16
Aluminum	0.17	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.00	0.20
Arsenic	0.005	0.006	0.006	0.006	0.005	0.004	0.009	0.009	0.006
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (total)	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.02
Copper	0.00	0.00	0.01	0.03	0.03	0.03	0.03	0.03	0.03
Iron	0.65	1.4	1.4	1.0	0.80	0.90	1.1	-	-
Lead	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.00	0.03	0.02	0.07	0.10	0.10	0.09	0.05	0.05
Zinc	0.00	0.02	0.03	0.17	0.20	0.23	0.13	0.11	0.10

Station	Location
BS01	Outlet Waite Pond, Leicester
BS08	Webster Street, Worcester
BS09B	American Steel Dam, Worcester
BS10	Millbury St., Worcester
BS12	Singing Dam, Millbury
BS13	Route 122A, Outlet Fisherville Pond, Grafton
BS14	Sutton Street, Northbridge
BS15	Riverdale St., Northbridge
BS16	Outlet, Rice City Pond, Uxbridge

III. Impact Assessment

A. Analysis of Sediment Data

In order to properly assess the significance of metals in the sediments of the Blackstone River, or anywhere else, it is important to understand the physical, chemical and biological mechanisms which govern the presence, transport and distribution of metals in the soil-water-biotic system. The following sections will discuss the fate and occurrence of metals in soil/water systems; identification of sediment standards/criteria; comparison of Blackstone River sediment data with sediment data from other locations; and the development and application of a sediment pollution index and severity ranking for the sites investigated on the Blackstone River.

A.1 Fate and Occurrence of Metals in Sediments

A.1.1. Occurrence of Metals in Sediments

Sediments are generally composed of rock material, organic materials and water. Geologic, meteorologic and hydrologic processes acting on the earth's surface supply minerals. Decaying organisms contribute organic matter. In addition, human activity increasingly alters the natural composition of sediments through waste generation. Both organic and inorganic matter is continuously discharged into natural water bodies. Therefore, we can distinguish the components of sediments according to their origins:

- . natural occurrence
- . anthropogenic occurrence

The average composition of the earth's crust has been estimated to be as follows:

SiO ₂	59.1%	Na ₂ O	3.7%
Al ₂ O ₃	15.2%	K ₂ O	3.1%
Fe ₂ O ₃	3.1%	H ₂ O	1.3%
FeO	3.7%	TiO ₂	1.0%
MgO	3.5%	P ₂ O ₅	0.3%
CaO	5.1%	rest	9.9%

Total: 100%

From these figures the "crustal abundance" of any naturally occurring metal can be derived.

The Clarke Number, a unit of the average abundance of an element in the earth's crust, was developed by geochemists. Since the "Clarke Number" reflects the average natural occurrence of metals in the earth's crust, it represents a reasonable means of estimating the natural background level of metals in sediments.

Table II-1 lists the Clarke Numbers (CN) of several of the most common elements. The average concentrations of these elements in river water, also developed on a global basis, are also listed in Table III-1.

A.1.2. Transport Mechanisms

The knowledge of the transport mechanisms of metals in natural water bodies is indispensable in evaluating the fate of metals in polluted aqueous environments. The chemical mechanisms that must be considered in studying the transport of metals in unpolluted rivers involve:

- . in solution and organic complexes
- . adsorbed on solids (ion exchange)
- . precipitated and coprecipitated on solids (coating)
- . incorporated in solid biological material
- . incorporated in crystalline structures

TABLE III-1

AVERAGE ABUNDANCES OF METALS IN THE EARTH'S CRUST
(REFERRED TO AS "CLARKE NUMBER") AND RIVER WATERS

<u>Metal</u>	<u>Clarke Number Earth's Crust mg/kg (ppm)</u>	<u>Average River Water $\mu\text{g/l}$ (ppb)</u>
Ag	.07	.3
Al	82,000	400
As	1.8	1.0
Ba	425	10
Cd	.1	--
Cr	100	1.0
Cu	55	5.0
Fe	56,000	670
Hg	.08	.07
Mn	950	5.0
Ni	75	.3
Pb	12.5	3.0
Se	.05	.2
Zn	70	10

A detailed examination of the mechanisms responsible for transporting metals in unpolluted rivers (R.T. Gibbs) reveals several interesting relationships. Two mechanisms -- involving metallic coatings and crystalline particles -- account for about 80% of the total of a given metal. The composition of the crystalline material, however, is dictated by the composition of the rocks of the river's drainage basin. Only about 20% of the total quantity of a given metal is transported by the remaining three mechanisms.

From the public health viewpoint, it is important to analyze for and know about the transport mechanisms. Metals transported in solution or adsorbed on solids are readily available. Metals present in organic materials or metallic hydroxides require chemical changes before they are released. Hence, they are less available. Metals present but incorporated in the crystal structure of the sediments are nearly unavailable in nature.

"Pollution", however, superimposes a different pattern of transport mechanisms to a water course. An increased organic content offers large surfaces for adsorption. High concentrations of trace metals are discharged into natural waters which become easily available due to unstable chemical bindings.

Therefore, knowledge about total amounts of metals in sediments is necessary for an assessment of the toxicity of those metals. It is important to note that sufficient information can only be gained through an analysis of the state of identify of a given metal (i.e., occurrence of chemical compounds in sediments).

A.1.3. Effects of Chemical Environment on Fate of Metals

Physical, chemical and biological parameters of the soil-water system all contribute to determine the chemical equilibria of metals in an aqueous environment. The following are examples:

- . pH determines the availability of hydrogen ions (H^+). Hydrogen ions compete with other ions (metals) for binding sites on the sediment functional groups. Increased pH means more binding sites available for metals, formation of metal-organic complexes increases. Also an increase in pH causes increased formation of metal hydroxides (MOH) thus increased precipitation.
- . Organic matter has a significant effect on the solubility of metals in soils. Higher organic content reduces the solubility of metals and increases the metal content in sediments.
- . Soil texture is an important factor for metal content and availability. Fine grained soils offer comparatively larger sorption potential than coarse material. A large grain surface means a high temporary storage system for soluble ions. It also means that metals are available in large quantities.
- . Aeration, soil moisture and soil temperature affect the solubility and consequently, the availability of metals to the environment (plants, animals).
- . The abundance of oxides, hydroxides, and clay minerals in most soils is the primary determinant of their ion exchange and adsorption mechanisms.

A.1.4. Pathways of Metals in the Soil-Water System

In a soil-water-biota system the fate of (heavy) metals is directly related to their states of identity and the existing environmental

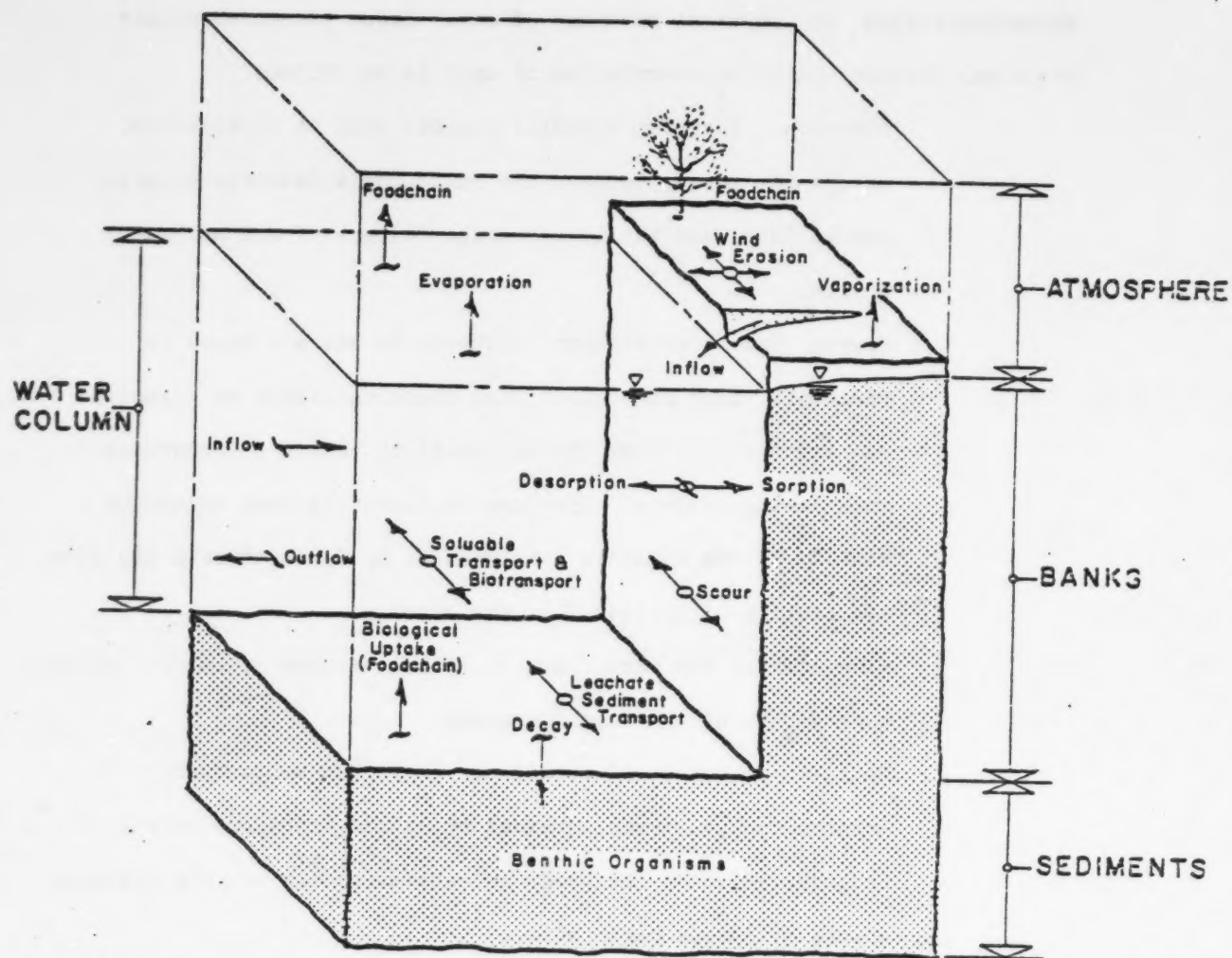


FIGURE III-1

PATHWAYS OF METALS IN
SOIL-WATER-BIOTA SYSTEMS

conditions. Principal pathways of contaminants (metals) are shown in Figure III-1. They include sorption-desorption, plant and animal uptake, bioconcentration, and physical movement of metal-laden suspended solids or animal tissues. A brief description of each is as follows:

- . Sorption: Sorption dynamics suggest that an equilibrium exists for metals between the solid phase (sediments, suspended load) and the liquid phase (water) of the soilwater system.
- . Uptake, Bioconcentration: Although metals are bound to sediments, they can desorb from those sediments or organisms can extract them from the sediments to become incorporated into living systems. They can be passed between organisms readily as one organism uses another as food. Metals are also available to organisms from the water.
- . Since metals bioconcentrate in animal tissues, they are subject to movement as the organism moves.
- . Metal-laden suspended solids represent the solid freight transported by rivers governed by hydrodynamic conditions. Erosion, sediment transport and sedimentation are the physical agents of solids dislocation.
- . Vaporization: Several metals can form extremely toxic metal salts. Vaporization and sublimation of these compounds, therefore, account for the release of the contaminants into the atmosphere.

A.1.5. Characteristics of Metals

The following sections provide brief outlines of the relevant environmental properties of metals included in this analysis (except aluminum, iron, and manganese). Table III-2 summarizes the acute and chronic toxicity levels of metals in freshwater.

TABLE III-2
TOXICITY LEVELS OF METALS IN FRESHWATER¹ (ppb)

<u>Metals</u>	<u>Acute Toxicity</u>	<u>Chronic Toxicity</u>	<u>Biomagnification in Tissue²</u>
As	-----	-----	reported
Cd	1	1	2,000
Cr ³	20	-----	-----
Cu	-----	-----	-----
Ni	2,500	430	-----
Pb	900	8	30,000
Zn	90	40	-----
Mg	-----	-----	63,000

Note: 1. Hard alkaline waters seem to reduce those values
 2. Reported in the literature up to given number
 3. Hexivalent Chromium for toxicity, total for CN water

ARSENIC

Occurrence: Arsenic is a naturally occurring element. The principal emission source for arsenic in the U.S. is thought to be coal-fuel power plants. The element is also used in industries like steel works, foundries, fertilizers, etc.

Physical Properties: Arsenic as a free element (As) is rarely encountered in natural waters. Elemental arsenic is virtually insoluble in water and the body fluids. Because of that, arsenic in its elemental state is of low toxicity.

Chemical Properties: The largest class of arsenic compounds are the organics, which are not naturally occurring. The two most common organic arsenic compounds are the arsonic acids, and the arsenic acids which both contain a variety of organic (alkyl) groups. Arsenic forms a complete series of salts. All of the arsenic salts are inorganic compounds that hydrolyze in the presence of water. The most toxic of these compounds is Arsenic hydride (AsH_3).

Toxic Effects: Arsenic has been shown to be toxic to both vertebrate and invertebrate freshwater aquatic organisms. Arsenic has been shown to bioconcentrate in both fresh and saltwater organisms. Although no animal experiments have demonstrated carcinogenicity of arsenic, several have shown that sodium arsenate (inorganic) induces developmental malformations in a variety of test animals including chick embryos, hamsters, rats and mice.

Data on exposure of humans points to a causal relationship between skin cancer and high level exposure to inorganic arsenic compounds. In addition, it was reported by researchers that symptoms of acute arsenic poisoning by ingestion causes abdominal pain and vomiting. Acute poison-

ing by inhalation produces giddiness, headache, extreme general weakness and, later, nausea, vomiting, colic, diarrhea, and pains in the limbs.

CADMIUM

Occurrence: Most fresh waters in the U.S. contain less than 1 ppb of cadmium. Cadmium reaches waterways as fallout from air and in effluents from pigments, plastics, alloys and other manufacturing operations as well as from municipal effluents. Cadmium is strongly adsorbed to clays, muds, humic and organic materials and some hydrous oxides, all of which tend to remove it from the water column by precipitation.

Physical Properties: The solubility of cadmium compounds in water depends upon the nature of the compounds and on water quality.

Chemical Properties: Cadmium dissolves readily in mineral acids (low pH). Cadmium is precipitated from solution by carbonate, hydroxide and sulfide ions and forms soluble complexes with other ions (ion exchange).

Toxic Effects: In the aquatic environment, cadmium is acutely . toxic to fish at concentrations as low as about 1 ppb. Chronic toxicity to fish has been reported at approximately the same levels. Water quality also affects cadmium toxicity independent of its effect on solubility. It has been shown that in acute tests calcium ion protects fishes against cadmium toxicity.

Cadmium has been reported to bioconcentrate in fish tissues to levels 2,000 times as great as those of ambient waters. Since cadmium is an element, it will not be destroyed (not degradable) and may be expected to persist indefinitely in the environment in some form. Cadmium tends to accumulate in liver and kidney of exposed organisms. In

humans the threshold for kidney disfunction is about 200 ppm in the renal cortex. Cadmium has been identified as a cause of Itai-Itai disease in Japan and has been implicated as a mutagen and carcinogen.

CHROMIUM

Occurrence: Chromium is a common element, present in low concentrations throughout nature. Although chromium is widely distributed, with an average concentration in the continental crust of 125 ppm (similar to Clarke Number), it is rarely found in significant concentrations in natural waters. Air levels in non-urban areas usually fall below detection limits and may be as low as 5 pg/m^3 . Much of the detectable Cr in air and water is presumably derived from industrial processes. Additional amounts are contributed by combustion of coal.

Physical Properties: Accumulation of the trivalent Cr is expected to occur in sediments since the compound tends to be adsorbed by MnO_2 . The hexavalent form will dissipate (leach) in soluble forms. The latter does not precipitate from alkaline solutions unlike most of the metal compounds.

For reasons of solubility uptake of the compounds of hexavalent Cr by living organisms generally exceeds that of trivalent Cr. This explains the greater toxicity of the hexavalent compounds, which are readily translocated across biological membranes. Once within the cell the compounds react with cell constituents such as proteins and nucleic acids.

Toxic Effects: The toxicity of Cr has long been recognized, but detailed analysis of toxic effects is complicated by the occurrence of many different compounds of these metals; these can be distinguished by their chemical, physical and toxicological properties.

In the fresh water environment, hexavalent Cr has been shown acutely toxic to invertebrates at concentrations as low as 22 ppb (in saltwater 2000 ppb) and 17.6 ppm (in saltwater - 30 ppm) for vertebrates. Hexavalent Cr is suspected of being carcinogenic.

COPPER

Occurrence: Copper is ubiquitous in the rocks and minerals of the earth's crust (Clarke Number is 55). In nature, copper occurs usually as sulfides and oxides and occasionally as metallic copper. Weathering and dissolution of these natural copper minerals results in background levels of copper in natural surface water at concentrations generally well below 20 ppb (see Table IV-2). Higher concentrations of copper are usually from anthropogenic sources like domestic sewage and industrial sources (smelting and refining industries, coal-burning, etc.). Exposure of plants, animals and humans to copper can occur from water, food (-chain) and air, and through direct contact of tissues with items that contain copper.

Chemical Properties: Elemental Cu is readily oxidized by organic and mineral acids. Salt compounds are common. Oxidized Cu is adsorbed on clays, sediments, and organic particulates and form various inorganic and organic compounds. The amounts of copper compounds in solution depends on water quality parameters like pH, temperature, alkalinity, etc.

Toxic Effects: Although copper poisoning in humans is rare, ingestion of milligram quantities of ionic copper can cause acute symptoms of nausea, vomiting and diarrhea. Many aquatic organisms are more sensitive than humans to Cu, and specific changes in the aquatic community may occur at copper concentrations significantly lower than those hazardous to human health. Copper occurs at higher concentrations in

freshwater than in sea water and is more toxic to aquatic life in soft acidic waters than in hard alkaline waters.

LEAD

Occurrence: Lead (Pb) reaches the aquatic environment through precipitation, fallout of lead dust, leaching from soil, street runoff, and both industrial and domestic wastewater discharges. Lead is ubiquitous in nature. The usual concentrations in rocks (lower) and in soils (higher) from natural sources ranges from 10 ppm to 30 ppm, with the Clarke Number being 12.5. The normal concentration of lead in rural vegetation ranges from 0.1 to 1.0 ppm dry weight. Thus, there is no noticeable degree of biomagnification in plants.

Physical Properties: The solubility of lead compounds in water depends heavily upon pH and ranges from about 10 ppt at pH 5.5 to 1 ppb at pH 9.0.

Chemical Properties: Bacterial action has been shown capable of converting inorganic lead to organic forms. Algae reportedly show a bio-magnification in their tissues of as much as 30,000 (compared to ambient water). Since lead is an element, it will not be destroyed and may be expected to persist indefinitely in the environment in some form.

Toxic Effects: In the aquatic environment, lead has been reported to be acutely toxic to invertebrates at concentrations as low as 450 ppb and chronically toxic at less than 100 ppb. The comparable figures for vertebrates are 900 ppb (acute toxicity) and 7.6 ppb (chronic toxicity). Toxicity is also affected by water hardness. Hard water is protective of organisms exposed to lead (alkalinity is beneficial).

Lead exposure has been reported to decrease reproductive ability in women and men. It has also been shown to cause disturbances of blood

chemistry, neurological disorders, kidney damage and adverse cardiovascular effects.

MERCURY

Occurrence: Several forms of mercury (Hg), ranging from elemental to dissolved inorganic and organic species, are expected to occur in the environment. The finding that certain microorganisms have the ability to convert inorganic and organic forms of Hg to the highly toxic methyl or dimethyl mercury has made any form of mercury potentially hazardous to the environment. In water, under naturally occurring conditions of pH and temperature, inorganic mercury can be converted readily to methyl mercury (highly toxic form as encountered in Minamata Bay, Japan).

Mercury can be bioconcentrated many fold in fish and other aquatic organisms because of rapid uptake and the relative inability of fish to excrete methyl mercury (MeHg) from their tissues. Freshwater values of magnification of 63,000 have been found as well as saltwater bioconcentration values of 10,000.

Physical Properties: Mercury is insoluble and is not attacked by water. Several forms of mercuric salts exist which have various degrees of solubility. The higher the solubility of a salt in water, the higher is the toxicity of those mercuric forms.

Toxic Effects: Non-human mammals have been shown to suffer central nervous system damage upon exposure to some forms of mercury. Tumors may develop as well. There is no data generated yet on the mutagenicity of inorganic mercury in human populations. There is no evidence of mercury exposure producing carcinogenicity. Mercury vapor is known to be toxic.

In humans mercury poisoning has been associated with neurological disorders, sensory impairment, ulceration, gastrointestinal complaints, etc. Mercurials will damage the bronchial epithelium and interrupt respiratory function in freshwater invertebrates. Rainbow trout will suffer loss of equilibrium, and trout fry are more susceptible to mercury poisoning than fingerlings.

NICKEL

Occurrence: Nickel enters the environment via both natural and anthropogenic activity. Its abundance in the earth crust is estimated at 75 mg/kg.

Toxic Effects: In the aquatic environment, nickel is acutely toxic to fishes at concentrations as low as 2,500 ppb. Chronic toxicity to fishes has been reported at 430 ppb. Water quality also affects nickel toxicity. Experiments have shown that fathead minnows are much more susceptible to nickel in soft water than in hard water (calcium carbonate).

A human health criterion is established on the basis of adverse effects seen in rats provided with drinking water containing 5 ppm nickel. These effects include reduction of litter size, increased numbers of runts, and increased neonatal mortality.

ZINC

Occurrence: Zinc is never found free in nature, but occurs as sulfide, oxide, or carbonate. Because zinc is an element, it can be expected to persist in the environment indefinitely in some form. Its Clark Number is 70.

Chemical Properties: Zinc is slowly oxidized in air, but moisture accelerates the rate of attack. Zinc reacts readily with mineral acids.

It also reacts with alkali hydroxides forming alkali zincates and hydrogen.

Toxic Effects: In the aquatic environment, zinc is acutely toxic to fresh water organisms at concentrations as low as 90 ppb. The lowest reported chronic effects are around 40 ppb. In marine waters, comparable values are somewhat higher.

Water quality has been shown to affect zinc toxicity. Hard water exerts a certain protective effect. Laboratory animals have been reported to tolerate zinc concentration up to 300 mg/kg in food.

A.2. Existing Standards & Criteria

At the present time, there are no standards for defining sediment quality characteristics in effect at either the state or federal level in the United States. The nearest established procedure that could be considered an action-level criteria in the U.S., is the EPA- Extraction Protection Toxicity Test, described in Section II. In reviewing the literature, Japan and Yokohama have adopted standards for the removal of toxic sediments. There is an abundance of literature and criteria which deal with the disposal of dredged material. However, all the criteria identified dealt specifically with the disposal of material dredged for navigation, construction or recreational purposes. None of the literature reviewed on dredging considered the in-place pollutant nature or impacts of the material to be dredged.

In addition to the criteria referenced above, there are other criteria or indices which can be used as guidelines in assessing the character of sediments. These include the Clarke Number (CN), University of Massachusetts Cooperative Extension Service recommended levels of chemicals in soils used for agricultural purposes, the "Jenson" criteria for the disposal of dredged material and the Region V EPA Great Lakes Sediment Rating Criteria. Table III.3 lists the numerical limits associated with each of these criteria. The criteria are discussed in the following sections.

Clarke Number

The Clarke Number (CN) has been defined in a previous section of this report. The CN may serve as a first order classification of sediments. It can certainly be expected that local geologic conditions will account for some deviation from that "average" number. A coefficient of variance of $Cv=100\%$ or greater might be expected for different watersheds, soil types, etc. Although the fact that the metals levels of a particular sediment

TABLE III-3

Summary of Existing Soils/Sediment Standards and Criteria

Element	Symbol	(1) Clarke Number	(2) EP- Toxicity	(3) Japan Solubility Test	(4) (1) Yokohama Criteria	(5) (2) Jensen Criteria	(6) Agriculture Criteria Unv.MA-CES	(7) (3) Great Lakes
Aluminum	Al	82,000	--	--	--	--	40	--
Arsenic	As	1.8	5.0	500	6 - 15	--	1.0	--
Cadmium	Cd	.2	1.0	100	4 - 24	--	.2	--
Chromium	Cr	100	5.0	500 (Cr ⁺⁶)	24 - 60 (Cr ⁺⁶)	--	--	--
Copper	Cu	55	--	--	--	--	1 - 6	--
Iron	Fe	56,000	--	--	--	--	3 - 20	--
Mercury	Hg	.08	.2	5	1.2 - 3.0	--	--	--
Manganese	Mn	950	--	--	--	--	3 - 15	--
Nickel	Ni	75	--	--	--	--	--	--
Lead	Pb	12.5	5.0	1,000	40 - 240	--	10	--
Zinc	Zn	70	--	--	--	--	3 - 70	--
Barium	Ba	425	100.0	--	--	--	--	--
Selenium	Se	.05	1.0	--	--	--	--	--
Silver	Ag	.07	5.0	--	--	--	--	--
UNITS OF MEASUREMENT		PPM (mg/kg)	PPM (mg/l)	PPB (µg/l)	PPM (mg/kg)		PPM (mg/kg)	--

(1) Refer to Table III-3 A for complete breakdown by soil type.

(2) Refer to Jensen Criteria Discussion.

(3) Refer to Table III-3B.

TABLE III-3 A

CRITERIA FOR REMOVAL OF TOXICSEDIMENTS AT YOKOHAMA

<u>Metal in ppm</u>	<u>Sandy</u>	<u>SOIL TYPE Silt, Clay</u>	<u>Organic</u>
Arsenic	6	10	15
Cadmium	24	4	6
Chromium*	24	40	60
Lead	240	40	60
Mercury**	1.2	2.0	3.0

* Hexivalent Chromium

** Total Mercury

location exceed the CN by some factor may not necessarily mean that the sediment represents an environmental hazard, it may indicate the need for additional tests besides bulk metals analysis (eg. EP-Toxicity, leachability/solubility, bioassay, etc.).

Extraction Procedure (EP) - Toxicity Test

This test procedure was defined in a previous section of this report. The criteria listed in the Federal Register, Vol. 45, No. 98, Monday, May 19, 1980 are listed in Table III.3.

Japan Solubility Test

The Japanese Environmental Agency, in 1977, set standards for the "Solubility Test" performed on sediments. The test procedure is as follows: Water and sediments are being mixed - Continuous stirring of the mixture is necessary for four hours - After a settling period the mixture is being filtered - Finally the analysis of the filtrate yields the solubility of a given metal the maximum allowable level of which is defined by the standard. The sediments are considered toxic when the solute concentration is greater than the standard. Those maximum levels are listed in Table III.3.

Yokohama Criteria for Removal of Toxic Sediments

Several local governments in Japan have developed or adopted their own standards for toxicity of sediments. An example is the City of Yokohama which established criteria for the removal of toxic sediments from its port.

The criteria are based on bulk sediment analysis according to three soil classifications. These criteria are presented in the following Table III 3 A.

Jensen Criteria

The Jensen Criteria were promulgated by EPA in 1971. They are presented here as an illustrative example of criteria for the disposal of dredged material. The criteria are outlined below:

<u>Sediments in Fresh and Marine Waters</u>	<u>Conc. % (dry wt. basis)</u>
*Volatile Solids	6.0
Chemical Oxygen Demand (C.O.D.)	5.0
Total Kjeldahl Nitrogen	0.10
Oil-Grease	0.15
Mercury	0.0001
Lead	0.005
Zinc	0.005

* When analyzing sediments dredged from marine waters, the following correlation between volatile solids and C.O.D. should be made:

$$\text{T.V.S. \% (dry)} = 1.32 + 0.98 (\text{C.O.D.\%})$$

When the concentration of any of the listed parameters in the material to be dredged (i.e., sediment) exceeds the criteria, the material is considered polluted and, therefore, unacceptable for open water disposal. Although the Jensen criteria establish a sediment material to be polluted, there is no consideration given to the pollution impacts of the sediment on its immediate environment. (e.g.; What impacts will this material have or continue to have on the local environment if we DO NOT dredge or otherwise treat it?).

At this time, the Jensen Criteria are not in use by Federal or State agencies due to technical weaknesses. The procedures did not take into account the location of contaminants in the dredged material, did not

address the availability of the contaminants to organisms and did not consider natural levels of the same constituents. Other criteria developed by EPA and the Corps. of Engineers are currently used to regulate the disposal of dredged material. The questions raised above, vis-a-vis the contaminant impacts of the material to be dredged if left in place, remain unaddressed by the present criteria.

University of Massachusetts Cooperative Extension Service -
Suggested Limits of Metals in Soils used for Agricultural Purposes.

The Cooperative Extension Service (CES) of the University of Massachusetts performed an analysis on Blackstone River soil samples to determine the soil's ability to support vegetation. The CES also supplied information on nutrient requirements for agricultural purposes including both essential and nonessential metals.

Column 6 of Table III-3 lists the recommended ranges of concentrations of available metals in soil. They are not limits on total content. The tests were performed and the recommended metal levels are included here because of their relevance to agricultural reuse of the sediments.

Great Lakes Sediment Rating Criteria

Guidelines for the evaluation of Great Lakes harbor sediment based on bulk sediment analysis, were developed by Region V of the U.S. Environmental Protection Agency. These guidelines were developed based on the need to make immediate decisions regarding the disposal of dredged material. As stated in the guidelines, they have not been adequately related to the impact of the sediments on the lakes and are considered interim guidelines until more scientifically sound guidelines are developed. Sediments are classified as non-polluted, moderately polluted or heavily polluted according to the criteria presented in Table III-3B.

TABLE III-3B
Great Lakes Sediment Rating Criteria

<u>Constituent</u> ¹	<u>Nonpolluted</u>	<u>Moderately Polluted</u>	<u>Heavily Polluted</u>
Volatile Solids (%)	5	5-8	8
COD	<40,000	40,000-80,000	>80,000
TKN	<1,000	1,000-2,000	>2,000
Oil & Grease (Hexane Soluble)	<1,000	1,000-2,000	>2,000
Lead	<40	40-60	>60
Zinc	<90	90-200	>200
Ammonia	<75	75-200	>200
Cyanide	<0.10	0.10-0.25	>0.25
Phosphorus	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	*	*	>6
Chromium	<25	25-75	>75
Barium	<20	20-60	>60
Copper	<25	25-50	>50
Mercury	*	*	≥1
Polychlorinated Biphenyls(PCB's)	*	*	≥10
SPI	5.3	---	6.3

1. All concentrations given in MG/KG Dry Weight except as otherwise indicated.

*No lower limits defined.

A.3 Sediment Pollution Index

Attempts to apply any of the criteria described in the preceding section to the data available on the sites investigated on the Blackstone River generally proved fruitless and can be summarized as follows:

1. Data for all stations tested on the Blackstone River generally exceed the Clarke Number, the Yokohana Criteria for removal of toxic sediments, the Jensen Criteria and the UMASS-CES Agricultural Criteria.
2. Based on the results of the EP-Toxicity Test, as previously discussed, none of the sediment deposits on the Blackstone River can be classified as in-place hazardous waste sites.
3. The Japan Solubility Test was not performed; thus no comparisons can be made.

As a means of qualitatively ranking the sediment pollution levels on the Blackstone River and provide a mechanism which will allow comparisons between conditions encountered on the Blackstone with sediment data from other areas, a sediment pollution index (SPI) was developed. The SPI utilizes the Clarke Number (CN) and the bulk sediment data available for the Blackstone River as well as several other locations in Massachusetts, other areas of the U.S. and in other countries.

Since CN reflects an average of all occurring rock types within the earth's crust one should expect a deviation from this number when sampling geologic materials (sediments) in a specific area of the world. Individual elements (metals) may occur more frequently at one location

(watershed) than at another.

The combined occurrence in the earth's crust of all the (trace) metals (not included are Al, Fe, Mg, Mn) is less than one tenth of one percent. Unless there are highly metallic geologic formations in the vicinity of a specific site, the natural occurrence of trace metals at that site is not expected to deviate significantly (less than a factor of two or three) from the combined CN ($\leq 0.1\%$). Hence, CN may be used as a standard for nonpolluted rock-forming minerals.

Metal contents of unpolluted sediments are expected to be lower than those of unweathered rock from the same watershed. The older the sediments and the more aggressive the chemical environment, the higher are the rates of leachate of mineral metals from the sediments. Hence, the Clarke Number is expected to be more like an upper limit for pollution-free metal contents in sediments.

Unpolluted organics within sediments will also contribute somewhat to the total metal content of a dried sediment sample, depending on the plant physiology of the species. The contents of metals relative to those of the crystalline component of the sediments are expected to be negligible, however.

Hence, pollution-free sediments composed of mainly inorganic matter (80% to 95%) and some organic matter (5% to 20%) are expected to contain metal concentrations less than or equal to those given by the Clarke Number.

Consequently, sediments containing higher metal concentrations than indicated by CN are an indication that they may be polluted.

A criterion on metal pollution based on the use of the Clarke Number can be formulated as:

$$\text{Pollution exists if } \frac{\bar{C} \text{ Metal}}{\text{CN Metal}} > f ,$$

where "f" is a factor whose magnitude may depend on a given metal. The term $\bar{C}$ metal stands for the statistical mean concentration of a given metal as derived from the total number of samples taken from the same deposits, and CN metal stands for the Clarke Number of a given metal.

Application of this principle to a number of metals occurring in a sediment sample yields the following Sediment Pollution Index:

$$SPI = \frac{1}{N} \sum_{i=1}^N \frac{\bar{C}_i}{CN_i}$$

Where: SPI = Sediment Pollution Index

N = Total number of metals included in calculating the SPI

$\bar{C}_i$ = Average concentration of metal i

CNi = Clarke Number of metal i

Adopting the above criterion for indication of pollution, one may call a site potentially polluted with a number (n) of metals, if:

$$SPI > F ,$$

where the threshold factor may be arbitrarily selected to be F=10, i.e., if the composite average metal occurrence exceeds its composite CN by a factor of ten, the site may be generally polluted with metals.

The term "pollution" must be appreciated since other labels such as "contamination" have a connotation of toxicity. The term pollution as used in above derivations must be distinguished from contamination or toxicity. "Pollution" merely describes the phenomenon of accumulation of a certain substance in a certain environment in exceedance of its

expected natural occurrence. Toxicity qualifies and quantifies the detrimental affect of the occurrence of a certain substance in a certain environment on that environment. Toxicity may always manifest pollution, but pollution does not necessarily imply toxicity,

Since toxicity depends on a multitude of environmental factors such as pH, concentration of certain chemical compounds, temperature, types of biota, and so on, it is extremely difficult to analytically derive a degree of toxicity from measurable environmental parameters.

As with any multi-parameter index, there are inherent advantages and disadvantages associated with its use.

Disadvantages are that the SPI is limited to consideration of metals, it does not take into account differences in substrate type (i.e., sandy soils, clay or organic matter), it can mask extremely high levels of one metal in the presence of low levels of other metals used in the Index, it does not necessarily relate to sediment toxicity, and it does not consider other pollutant such as pesticides and other organics or problems such as sediment oxygen demand.

Advantages to the use of the SPI are that a single number can be used to quantify a certain environmental condition of a small sample or an entire site; it provides a quantitative means of comparing data from several other sites and it provides a basis for qualitatively ranking the severity of metal pollution of sediments from several sites and/or different areas. Thus, one has a handy, if simplistic, tool available for evaulation and comparison of sediment conditions of different sites and areas.

A.4 Application of the Sediment Pollution Index to Blackstone River Sediment Data

Sediment Pollution Indices (SPI's) were calculated for each of the sites in the study area using the average concentration of each metal and at each site. Metals included in the SPI computation were arsenic, cadmium, chromium, copper, lead, nickel and zinc. The equation used to compute the SPI took the following general form:

$$SPI = \frac{1}{7} \left(\frac{\overline{As}}{1.8} + \frac{\overline{Cd}}{.2} + \frac{\overline{Cr}}{100} + \frac{\overline{Cu}}{55} + \frac{\overline{Pb}}{12.5} + \frac{\overline{Ni}}{75} + \frac{\overline{Zn}}{70} \right)$$

The average metal concentrations for each site and the computed SPI'S are listed in Table III-4. Aluminum and iron were not included in the calculations for the SPI's due to their relative natural abundance and the observation that the Clarke Number for these elements was rarely equalled or exceeded at any of the sites.

Again assuming that the SPI represents some degree of pollution severity, the sites investigated on the Blackstone River can be ranked as follows based on the SPI calculated for each site:

- | | |
|----------------------------------|----------------|
| 1. Site 3 - Singing Dam | Most Polluted |
| 2. Site 7 - Rice City Pond | |
| 3. Site 5 - Northbridge Mill Dam | |
| 4. Site 6 - Rockdale Impoundment | |
| 5. Site 4 - Fisherville Pond | |
| 6. Site 2 - McCracken Pond | |
| 7. Site 1 - Millbury St. | |
| 8. Site 8 - Lackey Pond | Least Polluted |
- 

Table III-5 was developed in the same manner as Table III-4 using sediment data collected by the Central Massachusetts Regional Planning Commission (CMRPC) 208 Water Quality Program in 1976 at several of the same sites on the Blackstone River as investigated by DEQE in this study. Although there are some differences, both data sets are generally in close agreement. Differences in the data can be attributed to several reasons including the number of sampling stations at each site; the sampling method (i.e., Core vs. Dredge); the fact that the CMRPC samples were composited in the field and the DEQE samples were analyzed as discrete samples then data averaged; differences in the location of sampling stations at each site and the extent of areal coverage at each site. Also, the CMRPC program sampled exclusively from the river bottom while the DEQE program included both River bank and streambed samples. A ranking of the sites using the SPI calculated from the CMRPC data is as follows:

1. Site 3 (BS09)	Singing Dam	Most Polluted
2. Site 5 (BS15)	Northbridge Mill Dam	
3. Site 4 (BS13)	Fisherville Pond	
4. Site 1 (BS09)	Millbury Street	
5. Site 7 (BS16)	Rice City Pond	
6. Site 2 (BS10)	McCracken Road	
		Least Polluted

Based on the data and SPI from both programs, Singing Dam contained the most severely polluted sediment on the Blackstone River. With the exception of Rice City Pond (Site 7), the severity ranking of both studies are reasonably similar. Table III-6 compares the SPI's computed for each site based on both the DEQE and CMRPC data.

TABLE III-4

Average Metal Concentrations and Sediment Pollution Index - DEQE - 1980

Element	(1) Site 1	Site 2	Site 3	Site 4	(2) Site 5	Site 6	(3) Site 7	Site 8
Arsenic	18.0	11.0	36.0	29.0	40.0	22.0	29.	8.0
Cadmium	16.0	43.0	48.0	29.0	33.0	40.0	50.0	1.0
Chromium	134	82	497	398	330	595	695	108
Copper	769	270	1311	914	3251	951	968	57
Lead	582.0	257.0	1091.0	814.0	1045.0	645.0	889.0	42.0
Nickel	192	69	110	73	67	65	106	14
Zinc	564	98	1144	667	681	1221	1022	232
SPI	23.2	35.6	56.3	36.8	49.1	43.6	53.9	2.6

1. Sample No. 1-2 - 1A not included.
2. Samples from channel not included.
3. Samples No. 7-1-5 (extreme low) and No. 7-6-1 (extreme high) not included.

TABLE III-5

Average Reported Metal Concentrations and Sediment Pollution Index - CMRPC, 1976

<u>Element</u>	<u>(Site 1)</u>	<u>(Site 2)</u>	<u>(Site 3)</u>	<u>(Site 4)</u>	<u>(Site 5)</u>	<u>(Site 7)</u>
Arsenic	-	-	5.00	2.00	0.48	-
Cadmium	32.00	9.20	100.00	37.00	65.00	17.00
Chromium	160.00	150.00	750.00	240.00	1100.00	210.00
Copper	176.00	200.00	1300.00	540.00	1100.00	220.00
Lead	160.00	150.00	980.00	340.00	1000.00	190.00
Nickel	51.00	40.00	2900.00 ⁽¹⁾	71.00	160.00	110.00
Zinc	320.00	140.00	1700.00	570.00	970.00	370.00
Mercury	0.89	0.71	0.48	0.40	0.36	0.52
SPI(w/o Hg)	30.5	10.9	106.1	33.5	64.6	18.9
SPI (incl. Hg)	27.7	10.6	91.8	30.0	57.0	17.1

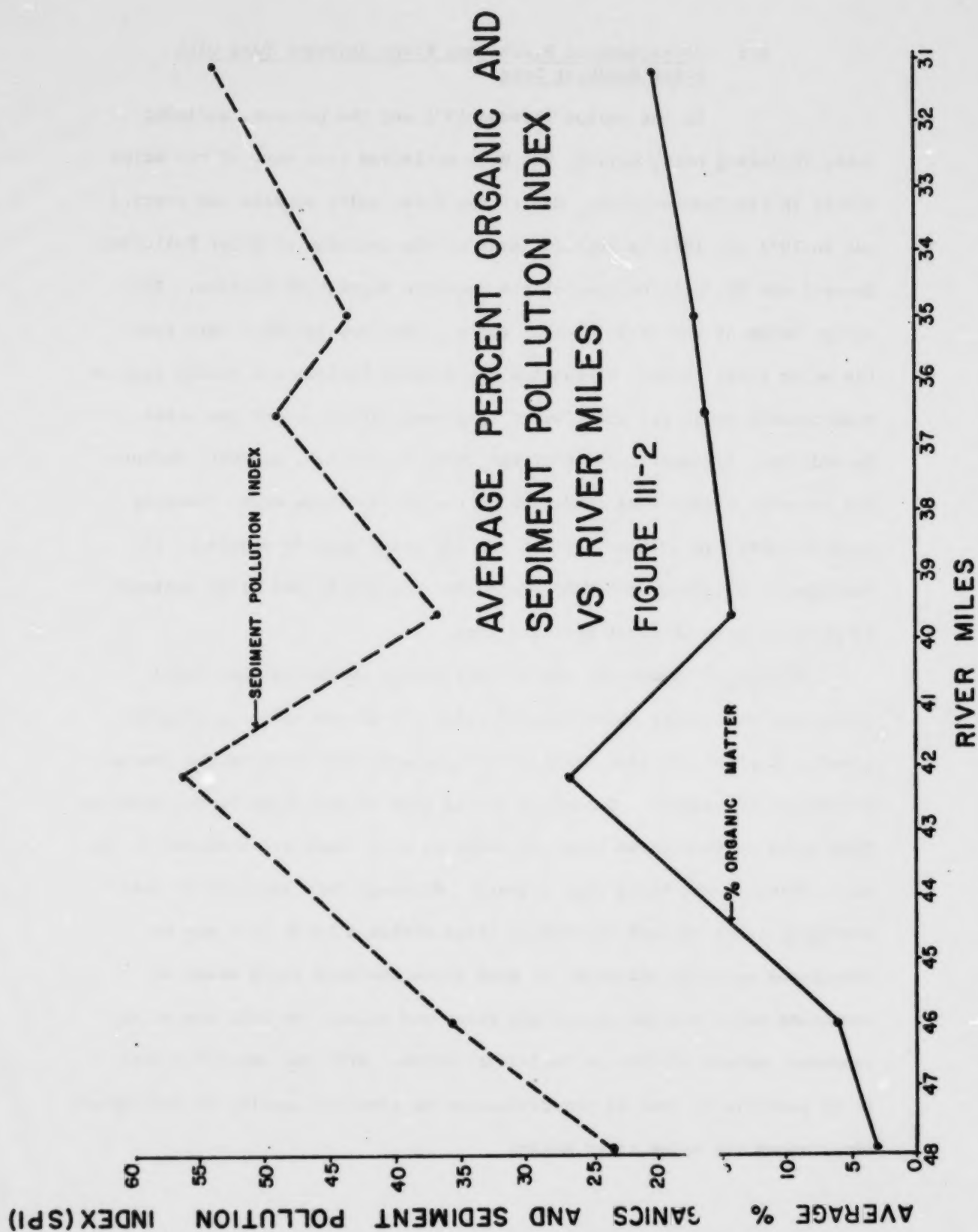
(1) Reported value suspect - not used in SPI computation (e.g. - N=6)

TABLE III-6Comparison of SPI using DEQE, 1980 and CMRPC 1976 Sediment Data

<u>Sampling Site</u>	<u>SPI DEQE 1980 DATA</u>	<u>SPI (1) CMRPC 1976 DATA</u>
Site 1 (BS09)	23.2	30.5
Site 2 (BS10)	35.6	10.9
Site 3 (BS12)	56.3	106.1
Site 4 (BS13)	36.8	33.4
Site 5 (BS15)	49.1	64.6
Site 6	43.6	—
Site 7 (BS16)	53.9	18.9

(1) SPI Computed w/o Mercury

Previously in this report, reference was made to the theoretical relationship between metals and the amount of organic matter in the sediments. Using the SPI in place of specific metals levels to compare with the percent organic matter found in the sediments at each site tends to strongly support this relationship. Figure III-2 plots both the average % organic matter and the SPI (on the same scale) versus river mile (site location). The shape of the SPI graph is very nearly identical to the shape of the average percent organic curve indicating that metals levels (and possibly chemical form and availability) are closely related to the amount of organic matter in the sediment.



A.5 Comparison of Blackstone River Sediment Data with
other Sediment Data

In the period between 1971 and the present, sediment data, including heavy metals, has been collected from many of the major rivers in the Commonwealth. One of the first major studies was carried out in 1971 and 1972 by Russell Isaac of the Division of Water Pollution Control and Dr. Jack Delaney of the Lawrence Experiment Station. This study, known as the Toxic Element Survey, included sediment data from the major river basins, Boston and New Bedford Harbors and sludge samples from several municipal waste water treatment plants around the state. In addition, sediment surveys of the Ipswich, Charles, Assabet, Sudbury, and Neponset Rivers were conducted by the Metropolitan Area Planning Council (MAPC) in 1976 as part of its 208 water quality program. As previously described, the CMRPC conducted its Blackstone River sediment sampling program at about the same time.

Table III-7 summarizes the average metals concentrations found throughout each river basin sampled under any of the sampling programs identified above and also displays a basin-wide SPI based on the average metals concentrations. Depending on the size of the river basin, anywhere from three to twenty-two sampling sites in each basin are included in the calculation of the basin wide average. Although this approach to data-averaging tends to mask individual sites within a basin that may be considered severely polluted, it does allow the most rapid means of comparing major regions around the state and allows the full use of an enormous amount of data on individual sites. With the available data it is possible to look at prioritization or severity ranking of individual sites among the major river basins.

TABLE III-7

Average Metal Concentrations in Sediments and Sediment Pollution Index by River Basin

	Ipswich ¹ River	Charles ¹ River	Assabet ¹ River	Sudbury ¹ River	Hop ¹ River	Neponset ¹ River
Arsenic	7.1	13.5	10.4	11.95	8.7	6.5
Cadmium	0.00	0.00	1.7	5.25	.48	.38
Chromium	11.3	22.3	109.5	204.75	11.2	37.8
Copper	-	-	-	-	-	-
Lead	17.25	44.3	147.1	147.75	30.0	166.2
Mercury	0.05	0.20	0.83	2.60	0.09	0.73
Nickel	5.8	4.0	19.7	22.6	13.1	30.0
Zinc	38.4	60.3	215.3	214.75	82.8	196.4
SPI	0.95	2.09	5.85	11.8	1.75	6.6
	Deerfield ² River	Farmington ² River	Hoosic ² River	Millow's ² River	South ² River	North ² River
Arsenic	.7	6.4	0.98	.73	.2	1.6
Cadmium	.24	.42	.53	.38	.16	.8
Chromium	4.5	4.2	7.6	8.7	6.2	12.4
Copper	24.6	7.9	25.6	46.0	6.7	10.4
Lead	17.8	19.2	30.3	37.2	26	98.1
Mercury	0.06	0.16	0.12	0.43	0.05	1.3
Nickel	6.1	6.2	7.25	3.4	3.6	8.1
Zinc	46.6	37.3	40.3	94.7	14.6	79.
SPI	0.62	1.25	1.04	1.63	0.51	3.82

TABLE III-7

Average Metal Concentrations in Sediments and Sediment Pollution Index by River Basin (continued)

	Westfield ² River	Taunton ² River	Town ² River	Ten Mile ² River	Bungay ² River	Salisbury ² River
Arsenic	1.45	6.7	4.5	2.0	0.0	5.0
Cadmium	.43	1.2	.35	11.9	.4	.85
Chromium	6.7	985.3	13.	203.	8.0	82.6
Copper	13.6	130.	13.9	585.9	12.4	14.8
Lead	12.0	112.	35.	88.3	305.	395.
Mercury	0.04	4.5	0.21	1.02	0.07	0.22
Nickel	11.5	23.7	3.5	234.3	7.5	4.5
Zinc	41.65	75.6	52.	154.5	70.	56.5
SPI	0.68	11.2	1.35	12.3	3.6	1.87
	Seven Mile ² River	Assonet ² River	Rumford ² River	Nemasket ¹ River	Blackstone ³ River	
Arsenic	.5	4.5	.6	0.0	26.4	
Cadmium	.5	.8	.3	.3	37.0	
Chromium	5.2	13.5	5.7	9.0	390.0	
Copper	23.2	19.5	12.	15.	1204.8	
Lead	32.5	157.5	34.5	27.5	760.4	
Mercury	0.17	0.25	0.06	0.16	-	
Nickel	9.3	10.8	6.8	4.3	97.4	
Zinc	51.5	65	40.5	38.5	771.	
SPI	8.85	2.97	0.80	0.83	42.65	

The comparisons afforded by Table III-7 indicate that the Blackstone River contains the most severely polluted sediment material of any major river in the state which has been sampled to date. On an individual site basis, there are locations on the Assabet, Sudbury, Taunton, Ten Mile, and Seven Mile Rivers which might be considered equal to or worse than any of the more polluted locations on the Blackstone River.

Table III-8 lists the sediment analysis and SPI's for fourteen other locations from other areas of the U.S., Canada and Japan. The following list identifies the water body, its location and, where possible, the source of waste corresponding to the columns a-o on Table III-8 :

- a. Minimata Bay, Japan - sea bottom sediments
- b. Duwamish Waterway, Washington - Bay sediments
- c. Port of Taganoura, Japan - paper mill waste
- d. Minimata Bay, Japan - salt lake, chemical industry
- e. Naka no Umi, Japan - electrical industry
- f. Tsurumi River, Japan -
- g. San Francisco Bay - sediments from undredged areas
- h. Baltimore Harbor - average of 19 sites, 3 depths
- i. Illinois
- k. Mississippi
- l. Ottawa
- m. Rideau
- n. Skeleton Creek
- o. Saddle River, New Jersey - lower reach, urbanized area.

Comparing the SPI's from the information in Table III-8 with the SPI's for the Blackstone River from Table III-7, no conclusions can be drawn as the SPI's from Table III-8 are either significantly lower or

higher than those for any of the sites on the Blackstone River.

In reviewing the data reported in connection with the various studies listed in Table III-8, it was interesting to note the range of SPI's over which various sediments were determined to be toxic to aquatic life and in the case of Minimata Bay, toxic to humans.

The Minimata Bay incident in the 1960's is perhaps the most well-known case of ecologic and human disaster directly attributable to heavy metal pollution ; in this case mercury. Over one hundred people died and hundreds more, including unborn and newborn infants, suffered permanent physical, mental and/or neurological damage as a result of ingesting fish which, in large part, fed off the mercury-contaminated sediments of Minimata Bay. As shown in columns "a" and "d" of Table III-8, Minimata Bay has the highest SPI of any location studied to date. When the SPI is calculated without the mercury values, it goes from over 500 to 31.3, which is comparable to the SPI levels of most of the sites investigated on the Blackstone River.

On the opposite end of the spectrum, Baltimore Harbor, (column "h" on Table III-8; SPI = 14.1) was found in certain areas to be highly or moderately highly toxic to certain forms of marine aquatic life, based on numerous bioassays. The SPI for Baltimore Harbor is well below those for the sites on the Blackstone, including those where some degree of toxicity was determined, as well as those which did not indicate any degree of toxicity.

Finally, it is interesting to note that applying the SPI concept to the criteria for removal of toxic sediments at Yokohama as presented earlier in this report yields sediment pollution indices of 31.6, 10.8 and 16.3 for sandy soil, silt (clay) and organic soils, respectively.

TABLE III-8

SEDIMENT ANALYSES AND SPI'S FROM SIMILAR STUDIES (mg/kg or ppm)

Identity of Study (a-o, see test)

Metal	Clarke Number	a	b	c	d	e	f	g	h	i	k	l	m	n	o
Al	82,000														
As	1.8	65	53						65						2.1
Cd	.2	1.7	2	148	21	7.3	1.5	.9	3.9						
Cr	100		61	128	357	36	96		456	17	12	22	21	5	26
Cu	55			322	913	31	222	.36	307	19	10	28	24	2	76
Fe	56,000			9910	44,100	29,930	63,000								12,873
Hg	.08	231	.3	.5	298	.5	.6	.7	1.1						
Mn	950			106	960	346	506		764						183
Ni	75			112	140	47	94		53						18
Pb	12.5	238	20	406	537	29	438	34	285	28	14	26	42	4	172
Zn	70			1320	1218	103	588	110	667	81	79	84	86	9	264
SPI		737.8	9.1	115.2	558.9	6.9	9.2	16.9	14.1	.98	.64	1.00	1.30	.14	5.0

* Iron was not included in calculation of SPI

These values are exceeded by most of the Blackstone River Sites. Baltimore Harbor falls between the silt, clay and organic soil type SPI which is consistent with the substrate types of Baltimore Harbor.

B. Analysis of Biological Data

B.1 Bioassay for Chronic Toxicity

As described in Section II.k, bioassays to determine chronic toxicity were performed on fathead minnows and Daphnia Magna using sediment samples from sites 3,4,5, and 7 on the Blackstone River. The results indicate that the sediments from sites 5 and 7 are toxic to Daphnia and that the sediments at all sites produced identifiable sub-lethal effects in the minnows. No apparent effects were observed in the Daphnia exposed to sediments at sites 3 and 4.

In examining the bulk sediment metals analyses for these sites, no correlation between total metal concentrations and the observed toxicity could be found. (refer to Tables III-4 and III-5). Table III-9 presents sediment elutriate data collected in conjunction with the CMRPC study previously described. The elutriate data is an indication of the leachability or mobility and shows the potential availability of a given metal. Only the elutriate levels of nickel and lead from sites 5 and 7 are consistently higher than those from sites 3 and 4. Copper levels are high at site 5 (.13 mg/l), low at site 3 (.05 mg/l) and equal at sites 4, and 7 (.10 mg/l). Cadmium levels are highest at site 5 (0.25 mg/l), slightly lower at site 3 (0.12 mg/l) and lowest at sites 4 and 7 (.05 mg/l). The same pattern is observed for zinc. Chromium is lowest at site 3 (0.00 mg/l), .02 mg/l at site 5, .03 mg/l at site 4 and highest at site 7 (.05 mg/l). However, the chemical species of chromium could be a significant factor with regards to toxicity. Hexavalent chromium is far more toxic than the trivalent form. No analysis of chemical species has yet been conducted. Except for the observation that lead and zinc are consistently

TABLE III-9 SEDIMENT ELUTRIATE ANALYSIS - CMRPC, 1976

Element (1)	BS09 (Site 1)	BS10 (Site 2)	BS12 (Site 3)	BS13 (Site 4)	BS15 (Site 5)	BS16 (Site 7)
Arsenic	-	-	0.00	0.00	0.00	-
Cadmium	0.03	0.05	0.12	0.05	0.25	0.05
Chromium	0.00	0.00	0.00	0.03	0.02	0.05
Copper	0.00	0.05	0.05	0.10	0.13	0.10
Lead	0.00	0.05	0.04	0.04	0.05	0.05
Nickel	0.04	0.05	0.20	0.10	0.25	0.30
Zinc	0.46	0.75	4.50	2.00	5.00	2.10
Mercury	0.0005	0.0004	0.0014	0.0004	0.0006	0.0005

(1) All analyses expressed as mg/l (ppm)

higher at the two sites with the highest mortality rates, the elutriate data is not significantly more conclusive than the total metals data. However, as discussed in section A.4 of this report, the data from Rice City Pond may not be representative of the entire site due to the number of samples taken and the location in the pond where the samples were taken. If the Rice City Pond elutriate data is discounted in the analysis, it can be concluded that levels of cadmium, copper, lead, nickel and zinc are significantly higher at site 5 and that the observed toxicity to *Daphnia* and fathead minnows might be attributable to any of these metals either alone or in combination.

Although the analysis of the flesh of the minnows used in this bioassay may help to pinpoint a specific metal or combination of metals as being responsible for toxic impacts, additional elutriate and leachability testing is clearly warranted.

B.2 Fisheries Survey

As described in Chapter II.L, a Fisheries Survey was conducted on the Blackstone River in May of 1981. A qualitative listing of the species of fish collected at each station is given in Table II-II. Analysis of the fish tissue samples was not complete as this report was being prepared. This information will be incorporated into the final version of this report.

As indicated by the qualitative listing in Table II-11, the upper reaches of the Blackstone, Kettle Brook, Stations 1 and 2, support a good fish population predominated by game species and pan fish. Trash fish such as white suckers and bullheads were few in number. This situation is reversed in the Middle River as indicated by Station 3. White sucker and bullhead were found in abundance almost to the exclusion of pan fish.

No game fish were found at Station 3. Due to the industrial/commercial-urban developed nature of the Middle River, it is difficult to attribute this population shift to water and sediment quality characteristics; loss of habitat due to intense urban development; or some other past environmental disaster which reduced the game fish population and/or severely limited its ability to re-populate this reach of stream. It is likely that all of these are factors.

Station 4 is located on the main stem of the Blackstone River, below the discharges from Mill Brook combined sewer (untreated), the Upper Blackstone Water Pollution Abatement District Treatment plant (secondary biological effluent) and the Millbury wastewater treatment plan (secondary biological effluent). The station is immediately above Singing Dam (Sediment Site 3). As might be expected, only a limited fish population was identified consisting predominately of trash fish. The might well be attributed primarily to water quality conditions imposed by the above-mentioned waste water discharges.

Some recovery is observed between stations 4 and 5. Although relatively few in number, bluegills and largemouth bass were collected at station 5. White sucker still tended to predominate in terms of numbers.

Station 6 is located on the Quinsigamond River, just above Fisherville Pond. A well-balanced population of pan fish including bluegills and pumpkinseed together with good numbers of bullheads and white suckers were found at this station, typical of fairly clean freshwater streams.

Only a small population of white suckers was collected at station 7 (immediately below sediment Site 5). This is likely due to a combination of causes including the absence of adequate cover and habitat, high flow conditions the day this station was sampled, limited food supply

and potential sediment toxicity. As indicated in the bioassay discussion, the sediments from site 5 proved toxic to Daphnia. It is reasonable to assume that the sediments in this locale are equally toxic to other aquatic zooplankton which are an important component in the food chain of pan and game fish species.

Considerable improvement in terms of both numbers and kinds of fish are observed between stations 7 and station 8 at Rice City Pond. Although the fish population was dominated by white sucker, a good number of small bluegill and pumpkinseed were collected. Based on the results of the bioassay and an ambient water quality conditions in Rice City Pond, it would appear that the sediments are the major limiting factor in terms of number of panfish and gamefish. This tends to be confirmed by the number and kinds of fish collected at station 8A, immediately below the outlet of Rice City Pond. White sucker (at this point the Blackstone River official fish) were still found, however, good numbers of bluegill, pumpkin seed and yellow perch, considered a clean water game fish, were also found at this station.

Station 9 had to be abandoned as high flow encountered during that day of the survey presented a safety hazard to the survey crew. Station 10 revealed a large and varied fish population clearly dominated by game fish and panfish. The effervescent white sucker was still in evidence. The recovery of the fisheries between stations 8 and 10 is consistent with observed recovery of the water quality characteristics of the Blackstone River over the same reach.

B.3 Plant Survey

A general plant survey was undertaken by C.E. Maguire biologists at sites 3 through 8. The data is tabulated in Appendix II. Generally,

the vegetation at sites 3,4,7, and 8 appear abundant and healthy while vegetation at sites 5 and 6 appears to be limited and is generally fair to poor condition. The following general site descriptions were prepared by Maguire staff:

Site 3: Singing Dam

GENERAL SITE DESCRIPTION: Primarily marsh and wetmeadow vegetation with areas of shrub, and mixed red maple and birch growth. Some patchiness in vegetation growth, localized downstream of Cross St. Bridge, on the southern shore. Growth fairly lush and healthy in appearance. 24 species identified.

Site 4: Fisherville Dam

GENERAL SITE DESCRIPTION: Primarily marsh and wetmeadow vegetation. In Quinsigamond area, water clear and vegetation lush, with aquatics abundant. In Blackstone area, water cloudy, no aquatics evident and some stream bank areas appear to have inhibited plant growth. Near dam, large areas covered by pickerelweed and duckweed. No noticeable algae growth.

Site 5: Northbridge Mill Dam

GENERAL SITE DESCRIPTION: This site is essentially unvegetated with limited growth of hydrophyllic grasses near river bank. Grading for the purpose of planting grass cover has been undertaken by the Town and this may be partially responsible for the lack of vegetation. Extremely low soil pH may also be limiting to plant growth (pH= 3.8 - 4.7) No aquatics were noted.

Site 6: Riverdale Dam

GENERAL SITE DESCRIPTION: Site divided into two vegetative areas. Area near dam is very patchy with large areas un-vegetated. Vegetation appears to be in fair to poor condition. Site upstream primarily wetmeadow vegetation with some marsh. Plants, in general, appear healthy, but there are patches where no vegetation grows. Stands of bottombush have died in one area. Algae present in standing water. Soil pH similar to Site 5.

Site 7: Rice City Pond

GENERAL SITE DESCRIPTION: Primarily marsh and wetmeadow vegetation with algae and some aquatics. Area looks basically healthy with less variety than might be expected.

Site 8: Lackey Pond

GENERAL SITE DESCRIPTION: Primarily marsh vegetation with some wetmeadow vegetation, the area has good variety and appears very healthy in growth.

C. Analysis of Heavy Metals in the Water Column

As part of an intensive water quality survey at the Blackstone River conducted in June, August and October, 1980 by DEQE and DWPC staff, heavy metals in the water column were analyzed at nine stations encompassing all at the sediment sampling sites on the main stem of the river. (Lackey Pond was not included). The Metals Data is tabulated in Table III-10. Also shown on Table III-10 are the metals levels in the effluent of the UBWPAD Treatment Plant.

Aluminum and arsenic concentrations are relatively low and does not appear to be influenced by wastewater discharges. Arsenic levels about double at stations BS14 and BS15, corresponding to sediment sites 5 and 6 respectively, suggesting that the increase is attributable to leaching from the sediments at these sites. The arsenic levels return to apparent "background" levels at BS16.

Cadmium and lead were not found at any station. Based on the CMRPC elutriate analysis, some cadmium was expected. However, it does not appear that cadmium is leaching from the sediments.

Chromium appears in the water column at stations BS12, 14, 15, and 16. The presence of chromium appears directly attributable to sediment leaching and not to any point source discharges. Although the chromium was found in the effluent from the UBWPAD plant, its presence in-stream would be expected to have been detected in the sample at station BS10.

Copper levels appear to be primarily related to the UBWPAD discharge. The observation that the copper levels remain constant in downstream stations suggest that some sediment leaching may be taking place. If the copper was attributed only to the waste discharge, it would be expected to decrease slightly in downstream reaches due to precipitation and dilution.

TABLE III-10

(1)
Heavy Metals in the Water Column - Blackstone River, 1980

	<u>BS01*</u>	<u>BS08</u>	<u>BS09B</u>	<u>BS10</u>	<u>BS12</u>	<u>BS13</u>	<u>BS14</u>	<u>BS15</u>	<u>BS16</u>	<u>UBWPA</u> <u>Dsc</u>
Aluminum	0.17	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	-
Arsenic	0.005	0.006	0.006	0.006	0.005	0.004	0.009	0.009	0.006	-
Cadmium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Chromium	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.0
Copper	0.00	0.00	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.0
Iron	0.65	1.4	1.4	1.0	0.80	0.90	1.1	-	-	
Lead	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Nickel	0.00	0.03	0.02	0.07	0.10	0.10	0.09	0.05	0.05	0.0
Zinc	0.00	0.02	0.03	0.17	0.20	0.23	0.13	0.11	0.10	0.6

(1) All analyses in mg/l

* Station Location

BS01 Outlet of Waite Pond, Leicester (Kettle Brook)
 BS08 Webster St., Worcester (Middle River, upper)
 BS09B American Steel Dam, Worcester (Middle River, lower)
 BS10 McCracken Rd., Millbury (Blackstone River, Sed. Site 2)
 BS12 Above Singing Dam, Sutton (Blackstone River, Sed. Site 3)
 BS13 Below Fisherville Dam, Grafton (Blackstone River, Sed. Site 4)
 BS14 Sutton St., Northbridge (Blackstone River Site 5)
 BS15 Riverdale St., Northbridge (Blackstone River, Sed. Site 6)
 BS16 Outlet of Rice City Pond, Uxbridge (Blackstone River, Site 7)

Iron, nickel and zinc also appear to be primarily influenced by either point sources and/or the degree of urbanization in the contributing drainage area. Based on the CMRPC elutriate data, significantly higher levels of zinc would be expected to leach from the sediments.

Table III-II lists the criteria for the 24 hour-average and maximum allowable concentrations of each metal listed. These are based on either the "Red book" criteria or the EPA Ambient Water Quality Criteria Series. The criteria listed correspond to the protection of aquatic life water use. In comparing the metals data in Table III-10 with the criteria in Table III-II; all the metals except copper and iron appear to be generally within the ranges suggested by the criteria.

TABLE III-II

Ambient Water Quality Criteria for Heavy Metals* - Protection of Aquatic Life

	(1) Site 3		(2) Site 4		(3) Site 5		(4) Site 7	
	24-hr. Avg.	Max	24-hr. Avg.	Max	24-hr. Avg.	Max	24-hr. Avg.	Max
Arsenic ⁵		50		50		50		50
Cadmium ⁶	.01	1.2	.01	1.7	.01	1.3	.005	.56
Chromium ⁵		100		100		100		100
Copper ⁶	5.6	9.4	5.6	13.0	5.6	10.5	5.6	4.9
Lead ⁶	.44	56.3	1.0	87.0	.6	65.0	.09	24.2
Nickel ⁶	48.0	919.0	62.4	1203.2	52.1	1005.32	28.1	543.0
Zinc ⁶	47.0	150.0	47.0	201.5	47.0	165.59	47.0	84.5
Mercury ⁶	.00057	.0017	.00057	.0017	.00057	.0017	.00057	.0017
Iron ⁶		1000	1000	1000		1000		1000

* All criteria given in $\mu\text{g/l}$

1. Hardness = 40 mg/l
2. Hardness = 57 mg/l
3. Hardness = 45 mg/l
4. Hardness = 20 mg/l
5. Based on EPA Red Book Criteria
6. Computed and/or given in EPA-Ambient Water Quality Criteria Series based on Hardness

D. Conclusions

Based on the preceeding Data Analyses, the following conclusions with regard to the magnitude and severity of sediment pollution and its impacts on aquatic and plant life in the Blackstone River and with regard to additional testing needs and the focus and direction of any forthcoming sediment management program can be drawn:

1. Sediments in the Blackstone River are grossly polluted with heavy metals.
2. Blackstone River sediments are collectively, the most severely contaminated sediments in the Commonwealth of Massachusetts.
3. Metals in sediment have been shown to be toxic to at least one specie of zooplankton.
4. Fisheries in the Blackstone are being adversely affected by the sediments, either directly or through impacts on food organisms or habitat.
5. Plant life in specific areas has been seriously impaired.
6. Although the sediment deposits do not appear to present a serious threat to human health, the health effect of heavy metals in sediments are neither well-documented nor understood. Therefore, steps should be taken to minimize exposure to the sediments particularly at Sites 3 - 7 inclusive.
7. In terms of developing a control strategy for the sediment condition in the Blackstone, initial efforts should focus on sites, 3, 5, 6, and 7.
8. Prior to implementing a sediment treatment and/or removal program, stream bank stabilization should be effected at sites 2,3,5, and 6 in order to prevent mass movement of exposed sediment and bank material.

9. Based on the volume of material and areal extent of the polluted sediments, control strategies at sites 5 and 6 should focus on in-place control/treatment measures.
10. Additional testing including: chemical speciation in bulk sediments of cadmium, trivalent and hexavalent chromium, total mercury, methyl mercury and alkylmercury, lead and copper; interstitial (groundwater) water monitoring (at sites 5 and 6); leachability and leaching rates of the above-listed metals and additional geotechnical investigations should be undertaken prior to selection of a final control strategy.
11. Based on the volume, areal coverage and in-stream location of polluted sediments, control strategies at sites 3 and 7 should include consideration of dredging to remove sediment.
12. Additional testing as in 10 above should be undertaken at sites 3 and 7 and should also include small-scale pilot studies of dredging methods and dredged material treatability and disposal/reuse alternatives prior to undertaking full-scale operations.
13. Additional bioassays should be performed with sediments from sites 3, 5, 6, and 7 using *Daphnia Magna* and Fathead Minnows. Bluegill, Pumpkinseed and /or Yellow perch should also be included as test organisms in one or more series of tests. Thirty day bioassays for chronic toxicity using flow-through techniques should be utilized. Also, side-by-side bioassays using sediment from the Blackstone River with a clean water source; using a clean sediment with Blackstone River water

and using Blackstone River water and Blackstone sediments should be conducted. These should be conducted by either the DWPC R & D Program or by the EPA Regional Laboratory in Lexington.

14. The Division of Water Pollution Control, Technical Services Branch, Biological section should conduct a benthic macroinvertebrate survey of the Blackstone River in 1982 to evaluate any changes that have taken place since the 1977 macroinvertebrate survey.
15. Tissue and organ analysis on higher order resident species such as frogs and turtles should be conducted at sites 3,4, and 7 and a control station in the Blackstone basin (e.g. Lake Quinsigamond or the West River).
16. Unless action is taken to control, treat or remove the sediments and their associated impacts on aquatic and plant life, water quality improvements, whether due to point or nonpoint source controls, cannot be expected to result in recovery of a warm-water fishery or other improvement in terms of recreational or other use of the Blackstone River.

IV. Control Alternatives, Impacts & Costs

This chapter is intended to outline the state-of-the art of available sediment control alternatives. In-situ control alternatives include physical stabilization, chemical stabilization and biological stabilization. Within each of these in-situ stabilization categories are a wide array of variations and further alternatives. Dredging to remove sediments from their present location is the other major control alternative. Within the dredging alternative are a number of alternative dredging methods in addition to a host of other considerations to be taken into account in considering dredging as a control option for a given site. A brief summary of the environmental impacts associated with each control alternative is also provided. Cost bases are developed for each control alternative which are subsequently used to generate costs for each alternative at each of the sites in the project area.

Much of the content of this chapter is taken directly from "A Preliminary Report on Bottom Deposit Removal and/or Control Alternatives for the Blackstone River " prepared for DEQE by C.E. Maguire for this project. The reader is encouraged to refer to Chapters V, VI, VII, VIII, and IX of that report for additional supporting information, particularly with regard to environmental impacts.

1. PHYSICAL STABILIZATION

Physical stabilization of contaminated soil/sediments is conceivable for both under-water and above-water application. The objective is to isolate the contaminated material from its environment such that any substantial exchange of contaminants is interrupted.

A wide range of materials is potentially useful as barriers for impounding hazardous solids and sludges. These liners vary considerably in permeability, durability, and cost. Selection of a liner (or combination

of liners) for a given installation depends upon many factors, such as the character of the contaminated materials (deposits) being contained, soil conditions, availability of materials, the level of performance required, the design life of the stabilization system and cost.

The selection of a liner material for physical stabilization of a site should involve the following considerations (EPA 600/2-77-081):

(a) The liner material should satisfactorily resist attack from all chemicals (solvents, oils, greases, etc.), ozone, ultraviolet radiation, soil bacteria, mold, fungus, and vegetation to which it will be exposed. Resistance can be determined by laboratory testing of the liner material in the industrial waste that the liner will contain.

(b) The liner material should have ample weather resistance to withstand the stresses associated with wetting and drying.

(c) The liner material should have adequate physical properties to withstand the stresses of installation and damage from machinery or equipment.

(d) The liner material should resist laceration, abrasion, and puncture from any matter that may be found in the material that it will contain.

(e) All the membrane material in a given installation should be of uniform thickness and of the same material furnished by the same manufacturer to ensure good seaming.

(f) A membrane liner should be free of gels, streaks, particles of foreign matter, and undispersed raw material. There should be no physical defects such as cracks, crazes, tears, or blisters. Pinholes should not exceed one per 8.4m^2 (10yd^2) of liner material.

(g) A membrane liner should be of sufficient thickness to guarantee long-term service in the specific application.

In the following, three different methods of lining are discussed. A summary is presented in Table IV-2. Types of slope protection are described also. Physical stabilization techniques can be divided into:

- (1) Synthetic flexible membrane liners
- (2) Natural soil systems
- (3) Admixed materials
- (4) Slope Protection

1. SYNTHETIC FLEXIBLE MEMBRANE LINERS

The most important advantages of flexible synthetic membrane liners for containment (stabilization) of contaminated materials are their ability to contain a wide variety of wastes with a minimum of loss from permeation and leaching, their high resistance to chemical, physical and biological (bacterial) deterioration, and their relative ease and economy of installation and maintenance.

Major disadvantages include the relative vulnerability of some liners to ozone and ultraviolet deterioration as compared with hard surface liners. The membranes' ability to withstand the stresses of heavy machinery is limited, compared with soils or admixed materials. Also, they are comparatively susceptible to laceration, abrasion and puncture from sharp objects such as stones and roots, etc. Some membrane materials are prone to crack and crease at very low temperatures and to stretch, creep and distort at very high temperatures.

The following is a list of commercially available synthetic lining materials:

- (a) Polyvinyl Chloride (PVC)
- (b) Polyethylene (PE)
- (c) Polypropylene

- (d) Butyl rubber
- (e) Chlorinated polyethylene (CPE)
- (f) Ethylene propylene rubber (EPDM)
- (g) Chlorosulfonated polyethylene (Hypalon)

A tabulation of general properties of these flexible membrane liners is presented in Table IV-1. It should be mentioned that all of those liners are also available with reinforcements such as yarns, fibers, and other densely materials. Thus, their physical resistivity can be enhanced significantly.

Membrane sheeting is usually made in a continuous process of plying together two thin sheets. Sheets are typically 4 to 5 feet wide and 200 feet long. Several of these sheets are seamed by a fabricator in a factory to form a panel. These panels are brought to the site and seamed in the field to make the final liner.

Several requirements should be fulfilled when designing and installing a stabilization system which is to be based on the application of synthetic liners. The thickness of the membrane is generally recommended to be no less than 20 mils (0.02"). Proper site preparation for synthetic liners is essential. The subsoil bed should be sufficiently prepared to ensure that all depressions, rocks, stumps, and other debris are eliminated. The subsoil should be sieved or the area raked after grading to provide a smooth, flat surface free of protrusions. If such preparation is not feasible or too costly (under water) a bedding of 12" of clean sand should be provided.

Gas control is a crucial element of an impermeable liner system. Decomposition within the encapsulated matter will occur under anaerobic conditions. Organic materials are broken down by microbial fermentation

TABLE IV-1
GENERAL PROPERTIES OF FLEXIBLE MEMBRANE LINER MATERIALS

Property	Polyethylene Low Density	Polyethylene High Density	Polyvinyl Chloride*	Chlorinated Polyethylene	Poly- propylene	Butyl Rubber	Hypalon	Ethylene-Propylene Rubber (EPDM)
Specific Gravity	0.92-0.94	0.94-0.96	1.24-1.30	1.35-1.39	0.9-0.91	0.92-1.25	1.4-1.5	1.15-1.21
Tensile strength, psi	1,300-2,500	2,400-4,800	2,500-3,500	1,800	4,000-32,000	1,000-4,000	1,000-2,000	1,300-1,500
Elongation, %	200-800	10-650	250-350	375-575	40-400	300	300-500	300
Shore "A" Hardness	**	**	55-75	65-75	**	45-80	55-95	50-70
Operating Temper. range, °F	-70 to 180	-70 to 240	-60 to 200	-40 to 200	-60 to 220	-50 to 325	-45 to 200	-75 to 300
Resistance to Acids	P-G	G	G-E	G-E	G-E	G	G	G-E
Resistance to Bases	G-E	G-E	G-E	G-E	G-E	G	G-E	G-E
Resistance to Oxygenated solvents	P-G	P-G	G	P	P	G-E	G	G-E
Resistance to aliph. and halogenated solv.	F-G	F-G	G	P	G	P	F	P
Resistance to aliph. (petroleum) solvents	F-G	F-G	G	G	G	P	G	P
Water vapor permeab. perm-mils	3-14	1.8-2.2	3-18	0.04-0.048	0.25-1.0	0.15	2.0	2.0
Weatherability	P-w/o black	P-w/o black	P-F	E	P-w/o black	G	E	E
Time to crack, hr.	900	300	no crack to 2,500	no effect to 4,000	100	no effect after 2,500	no effect after 1,000	no effect after 1,000
Time to chalk, hr.	no effect to 2,500	500	300	no effect to 4,000	500	no effect after 2,500	no effect after 1,000	no effect after 1,000
Time to fade, hr.	300	300	100	no effect to 4,000	900	no effect after 2,500	no effect after 1,000	no effect after 1,100

*plasticized PVC

**Data not available. P is poor, F is Fair, G is good, and E is excellent. ASTM test methods for various properties:
specific gravity, D-751; tensile strength, D-97-61T; elongation, D-412-61T or D-882; shore "A" hardness, D-676-59T;
water vapor permeability, E-96-66.

Source: EPA-600/2-78-196 "Protective Barriers for Containment of Toxic Materials," Fung, 1980.

Table VI-2 (CONTINUED)

<u>Material and Description</u>	<u>Advantages</u>	<u>Disadvantages</u>
	(e) Low spray on temperatures 60°-150°F (15°-65°C) for RT 1,2,3, and 4 and RTCB 5 and 6.	
	(f) Provide hard, tight, stable surface membrane (RT 7,8, and 9). May be used in flat areas or on slopes.	
	(g) Provide good penetration, then cure to form hard surface (RTCB 5 and 6).	
<u>Synthetic Membranes</u>		
<u>Bituminous fabrics</u>	(a) Require minimal special equipment and skill	(a) Expensive.
	(b) Resist tearing.	(b) Laps should be sealed.
<u>Commercial polymeric membranes (butyl rubber)</u>	(a) Available in various size sheets.	(a) Poor resistance to weathering & abrasion.
	(b) Can be reinforced with fibers for added strength	(b) May be damaged by gnawing/burrowing animals if not protected with soil.
	(c) Can be joined at seams to cover large areas.	(c) May be damaged by heavy equipment operating directly on surface and may be punctured by large stones or sharp edges in direct contact.
	(d) Good availability.	
	(e) Good heat resistance.	
	(f) Very low water permeability.	
	(g) Low vapor transmissivity.	
<u>Neoprene rubber (Chloreprene rubber)</u>	(a) Good resistance to oils, grease, gasoline, acids, and alkalies.	(a) More expensive than other natural and synthetic rubbers.
	(b) Good resistance to abrasion, weathering, and flexing.	(b) Use is limited to special applications because of (a) above.
	(c) Can be joined at seams to cover large areas.	(c) May be damaged by gnawing/burrowing animals if not protected with a soil layer.
	(d) Can be reinforced with fibers for added strength.	
	(e) Very low water permeability.	(d) May be damaged by heavy equipment operating directly on surface and may be punctured by large stones or sharp edges in direct contact.
<u>Hypalon (chlorinated chlorosulfonated polyethylene)</u>	(a) Outstanding resistance to abrasion and weathering.	(a) May be damaged by gnawing/burrowing animals if not protected with a soil layer.

Table IV-2 (CONTINUED)

<u>Material and Description</u>	<u>Advantages</u>	<u>Disadvantages</u>
Hypalon (chlorinated chlorosulfonated polyethylene)	(b) Available in various size sheets. (c) Can be fiber reinforced for added strength. (d) Can be joined at seams to cover large areas. This can be done on site or at factory. (e) Very low water permeability.	(b) Not satisfactory when exposed to amyl acetate, C_6H_6, CCl_4, creosote oil, cyclohexane, dioctyl phthalate, ethyl acetate, oleum, lacquer, $C_2H_2Cl_2$, naphthalene, $C_6H_5NO_2$, $C_6H_5CH_3$, tributyl phosphate, C_2HCl_3, turpentine, and $C_6H_4(CH_3)_2$. (c) For good seam quality sun at $> 50^\circ$ or application of heat to seams is required. (d) May be damaged by heavy equipment operating directly on membrane. (e) May be punctured by large stones or sharp edges in direct contact.
Polyolefin (polyethylene and chlorinated polyethylene)	(a) Available in various sizes. (b) Can be joined at seams to cover large areas. (c) Can be fiber-reinforced. (d) Chlorinated polyethylene has excellent outdoor durability. (e) Very low water permeability.	(a) May be damaged by gnawing/burrowing animals if not protected by soil. (b) May be damaged by heavy equipment operating directly on membrane. (c) May be punctured by large stones or sharp edges in direct contact. (d) Polyethylene has poor durability when exposed.
Elasticized polyolefin 3110	(a) Can be seamed to cover large areas. Field bonding is done by heat seaming. (b) Excellent resistance to soil microorganisms, extremes of weather, and ozone attack. (c) Very low water permeability.	(a) May be damaged by gnawing/burrowing animals if not protected by soil. (b) May be damaged by heavy equipment operating directly on membrane. (c) May be punctured by large stones or sharp edges in direct contact.
PVC (Polyvinyl chloride)	(a) Fair outdoor durability. (b) Available in sheets of various sizes. Factory seaming available. (c) Seams can be bonded in the field with vinyl to vinyl adhesive. (d) Generally used without reinforcement, however, can be fiber-reinforced for special applications. (e) Very low water permeability.	(a) May be damaged by gnawing/burrowing animals if not protected by soil. (b) For extended life, must be covered with soil or other material. (c) May be damaged by heavy equipment operating directly on surface or large stones or sharp edges in direct contact. (d) Not as durable as Hypalon or chlorinated polyethylene.

Source: EPA-600/2-79-165
 "Protective Barriers for
 Containment of Toxic Ma-
 terials".
 Fung 1980.

Table IV-2
PRODUCTS RECOMMENDED FOR HIGH-PRIORITY COVER

Material and Description <u>Admixed Materials</u>	<u>Advantages</u>	<u>Disadvantages</u>
Bitumen cements or concretes (AC-40 and AC-20 viscosity grades).	(a) Provide tight, impervious barriers covering municipal/hazardous waste. (b) Good availability. (c) May be used as thick waterproofing layers in flat areas or on slopes.	(a) Expensive (b) Special heating and storage equipment required for handling. (c) Vulnerable to breakin.
Portland cements or concretes (3,000 psi and 5,000 psi)	(a) Good availability (b) Provides good highly impermeable containers or covers or hazardous waste disposal. Very low water permeability.	(a) May crack during curing, allowing potential paths for escaping gases or infiltrating water. (b) Leakage from hazardous wastes in liquid form may weaken concrete with time.
Liquid and emulsified asphalts (RC and EC 30,70,250,800, and 3000 liquid asphalts. RS's and CRS's 1 and 2 MS's and CMS's 2, and SS1 emulsion).	(a) Can be sprayed on soil covers to decrease water and gas permeability. (b) Can be mixed with soil to form waterproof layer. (c) Penetrate open surfaces, plug voids, then cure. (d) Penetrate tight surfaces, plug voids, then cure. (e) Provide hard, tight, stable membrane (RC and MC 800 and 3000).	(a) Must leave sprayed surface exposed until it either cures (RC's MC's) or sets (SS's). (b) Must be covered for protection. (c) Require additional equipment to handle and apply the asphalts. Spraying temperatures range from 75° to 270°F (25° to 130°C). (d) Use of RC and MC 800 and 3000 in thick membrane construction may require numerous applications.
Bentonite	(a) No special equipment needed. (b) Can be mixed with soil.	(a) Difficult to handle and spread after wetting. (b) Susceptible to shrink-swell.
Tars (RT 1,2,3,4,7,8 and 9. RTCB5 and 6).	(a) Can be sprayed on soil surfaces or mixed with particles. Tars mix well with wet aggregate. (b) Penetrate tightly bonded soil surfaces and plug voids (RT 1 and 2). (c) Penetrate loosely bonded fine aggregate surfaces and plug voids (RT 2, 3, and 4). (d) Penetrate loosely bonded coarse aggregate surfaces and plug voids (RT 3 and 4).	(a) Tar may be removed by traffic if not covered with a protective soil layer. (b) Tars are more susceptible to weathering effects than asphalts. Must be protected from weathering. (c) Require special equipment for handling and application (d) RT 7,8 and 9 require special application temperatures of 150° to 225°F (65° to 105°C).

and gases are being generated. A system of pipe should be installed or a layer of porous matter (gravel) should be placed underneath the synthetic membrane to allow for controlled gas flow and relief of hydrostatic pressure differentials.

Anchor trenches should be a minimum 6" deep and placed alongside any side slope.

To prevent erosion, mechanical damage to the liner, and hydraulic lifting, a minimum backfill of 12" sand or fine textured soil on top of the liner is recommended. The surface should be dressed up with a layer of topsoil, and riprap along banks, to allow for the recovery of natural habitats. In case of underwater application the grain size of the cover material should be chosen to withstand the sheet stresses exerted on the bottom by currents and windinduced wave motion.

A schematic of a typical synthetic liner system is shown in Figure IV-1.

2. NATURAL SOIL SYSTEMS

Layering of several different types of natural soils is also a very useful technique for designing a physical stabilization system. Depending on the site conditions, submerged or exposed sediments, several variations are conceivable.

COMPACTED SOILS: The characteristics of a soil suitable for compaction include low permeability, high stability, and good resistance to erosion.

The moisture level in a soil affects the degree of compaction, and consequently, the permeability. An optimum moisture level exists for maximum compaction, after which increased permeability occurs. Hence, it is clear that underwater application is only feasible if substantial

leachate through the soil layers is not expected because of the thickness of the layers or the high sorptivity of the soil (see Chemical Stabilization). Similarly, application to exposed sediments is only feasible if storm water can be drained and diverted.

Because soil permeability is inversely proportional to the thickness of the compacted soil layers, the soil should be compacted in 6" layers up to a depth of 3 ft. But even under the most optimum conditions of compaction, permeabilities may change over a period of time.

Instead of layering only compacted granular material (gravel and sand), it is also conceivable, of course, to increase the impermeability of the liner system by installing a layer of clayey material. Composition and thickness of this layer can be adjusted to the specific site conditions.

Specifications for construction and/or placement of a soil seal should be based upon results of a preliminary testing program. Topsoil should cover the compacted soil layers to provide the environment for accelerated ecological recovery. A schematic is presented in Figure IV-1.

SOIL BENTONITE: Bentonite is distinguished from other clays by its extreme fineness, high absorbency, and property of swelling in water. High swell clay minerals have been widely used to control excessive seepage in natural soils by decreasing their permeability.

A soil bentonite system represents somewhat of a compromise between an impermeable synthetic membrane system and a permeable compacted soil system. It combines the advantage of impermeability with the concept of a layered natural soil system. Favorable characteristics of each are retained.

Bentonite has the capacity of absorbing approximately five times its weight in water and occupies a volume of up to 15 times its dry bulk volume at maximum saturation. It is this swollen mass that fills and

seals the voids in soils that normally would permit water seepage. It should be noted, however, that the chemical composition of some wastes (deposits) may adversely affect the swelling and sealing ability of bentonite.

Installation under water may be difficult if not unfeasible. More research is necessary.

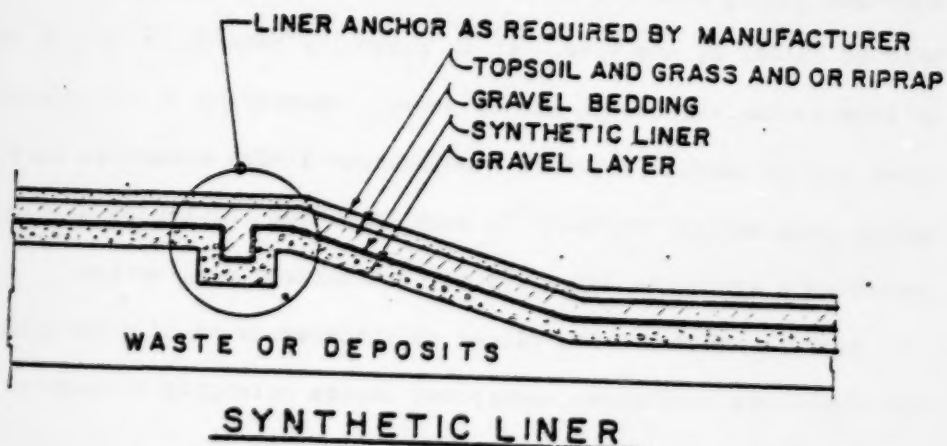
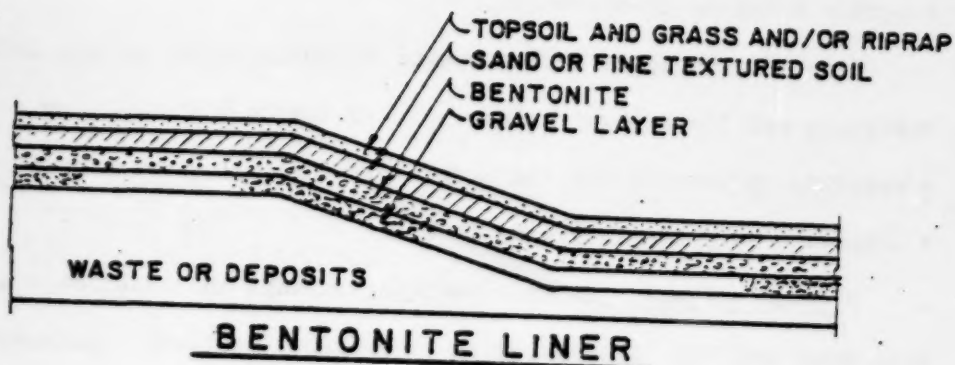
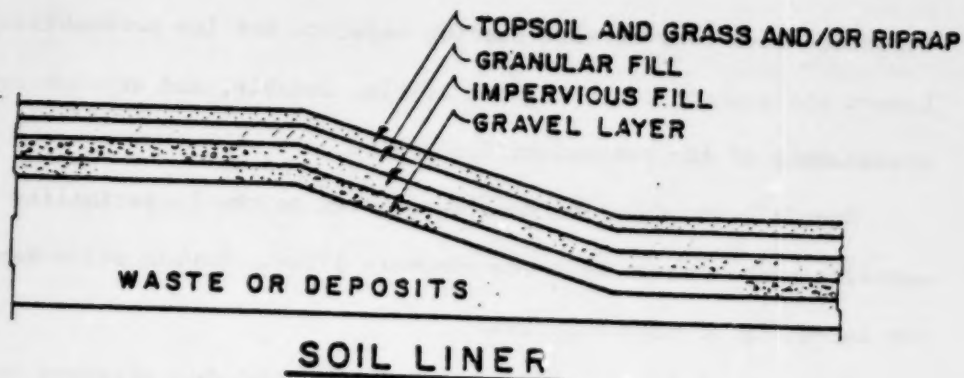
Preliminary testing of proposed bentonite seals is recommended. Specifications for the liner system should be based upon results of the preliminary testing program. Specifications for construction and/or placement of the system should also be based on test results.

Due to the sealing effect of soil bentonite, provisions for gas control similar to those mentioned earlier are recommended. Again, topsoil, loam or USAS types of soil, made amenable to supporting vegetation and developing a natural habitat should form the top of a layered soil bentonite system. A schematic is shown in Figure IV-1.

3. ADMIXED MATERIALS

The possibilities of using admixed materials such as concrete, asphalt concrete, bituminous seal, soil asphalt, and sprayed asphalt membranes as linings have been recognized. The primary advantages of these materials are their universal availability, low cost, extreme versatility in available physical forms, and the fact that they are some of the most logical engineering materials available for large scale sealing and encasement projects.

CONCRETE: Both cement and asphalt concrete are carefully controlled mixtures of the binding agent (cement, asphalt) and graded aggregate that are placed and compacted under specified conditions (temperature, moisture, etc.). If properly based on well compacted gravel bedding, placement of a layer of concrete can provide a lining



NOTE: Design for Soil and cover depth are subject to actual site conditions. Also not shown are measures to control gas.

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FIGURE IV-1

STABILIZATION WITH LINERS

structure with considerable bearing capacity and low permeability. Cement and asphalt concrete form stable, durable, and erosion-resistant encasements of the contaminated deposits.

Special consideration should be given to the compatibility of site specific contaminants with the concrete liner. Strong acids may endanger the integrity of such a system.

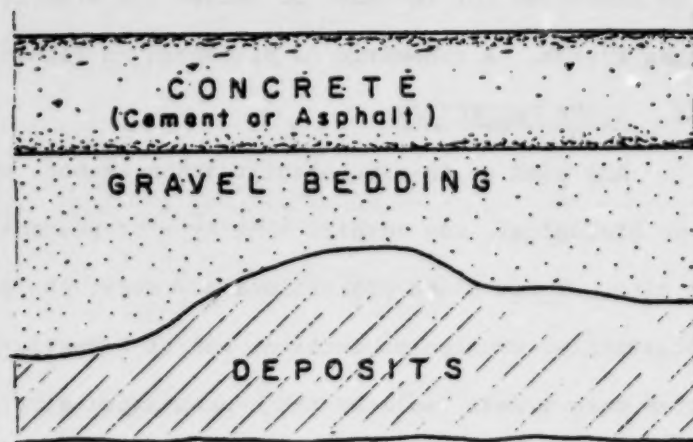
Temperature fluctuations can exert considerable stresses on cement concrete encasements. If cracks are to be prevented, or limited, some reinforcement may have to be required. This, however, can make a cement concrete solution uneconomical.

General principles such as those in publications of the Asphalt Institute and the Highway Research Board may be followed when designing a concrete encasement for the purpose of physical waste stabilization. A schematic is shown in Figure IV-2.

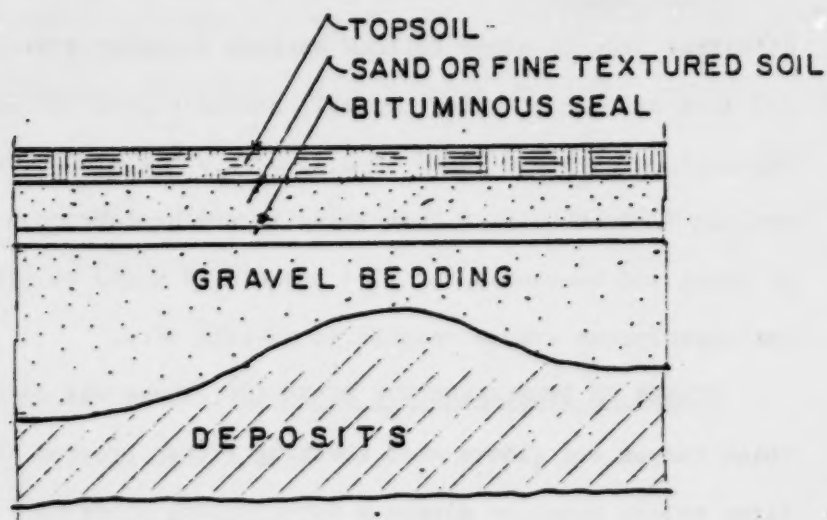
SPRAYED ASPHALT: Asphalt membrane linings and bituminous seals have been used for waterproofing of granular surfaces. An asphalt membrane lining consists of a continuous layer of asphalt, usually without filler of any kind. It is generally covered or buried to protect it from mechanical damage and to prevent weathering of the surface. The cover may be another layer of a multilayer lining structure such as native soil and/or topsoil. In such formation the lining system strongly resembles a synthetic liner system or a natural soil system.

Asphalt membranes are placed to thicknesses of 3/16 to 5/16 inch and constitute continuous waterproof layers extending throughout the length and breadth of the site being lined.

Bituminous seals are similarly sprayed over the lining surface. This method provides a film approximately 1/32 inch thick. Several layers can be placed on top of each other.



CONCRETE ENCASEMENT



ASPHALT LINING

NOTE: Design for Soil and cover depth are subject to actual site conditions. Also not shown are measures to control entrapped gas.

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FIGURE IV-2

STABILIZATION WITH LINERS

Due to the sealing effect of sprayed asphalt, gas generation and flow must be accounted for in order to secure the stability and integrity of the lining system. A schematic is presented in Figure IV-2.

4. SLOPE PROTECTION

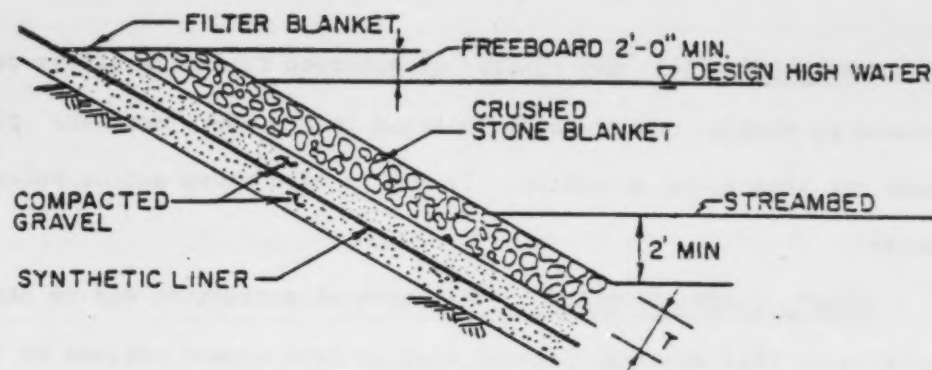
Any kind of in-situ stabilization method, whether physical, chemical, or biological, may require some type of protection of the slopes and banks on a site. These slope protections may serve the purpose of physical slope stabilization, erosion protection, and/or a barrier against leachate. In the latter case a seal isolates the contaminated site from adjacent environments such as surface water or unpolluted areas.

Slope protection may consist of one or a combination of the following methods:

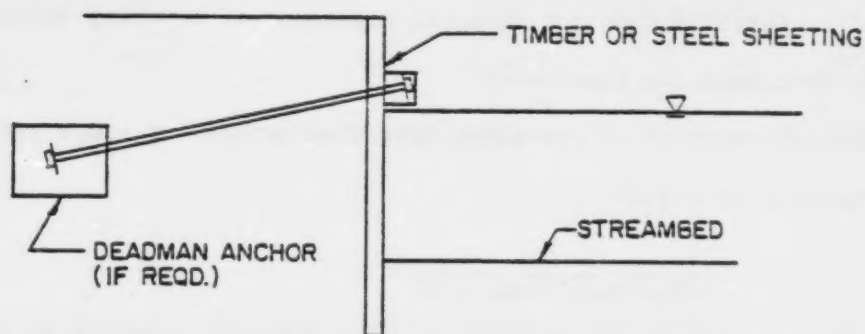
STONE BLANKET: This may consist of an 18 to 24-inch thick layer of either crushed stone (3 inch maximum diameter typical), heavy gravel (12 inch maximum diameter typical) and/or riprap (18 inch maximum diameter typical). The stone would be placed on a prepared bedding which may include 12-inch thick filter layer(s) and/or fabrics to prevent crossing of fines and contaminants. The stone used would be sized to be stable for anticipated stream velocities at each site.

TIMBER OR STEEL/ALUMINUM BULKHEAD: These may consist of 3 inch thick tongue and groove wood sheeting either treated or untreated or light weight steel or aluminum interlocking sheeting. The bulkheads may be self supporting cantilever or be tied back with a dead man anchor.

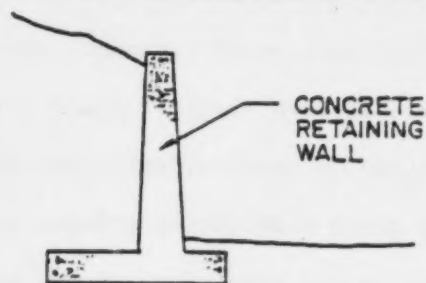
RETAINING WALL: This consists of a reinforced concrete structure to provide protection to relatively steep banks and is similar in application to timber and steel bulkheads.



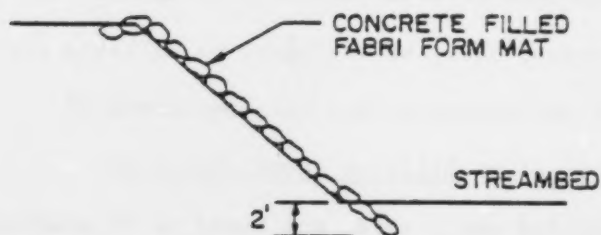
A - STONE BLANKET AND TOE TRENCH DETAIL



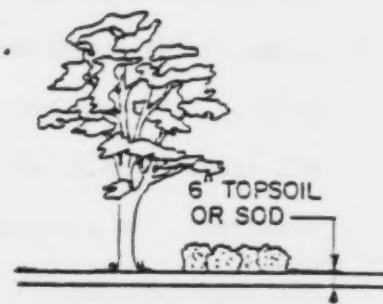
B - TIMBER OR STEEL/ALUMINUM BULKHEAD



C - CONCRETE RETAINING WALL



D - REVETMENT



E - GRASS, TREES & SHRUBS

FIGURE IV-3
SLOPE PROTECTION
BLACKSTONE RIVER SEDIMENT STUDY
NOT TO SCALE

REVEITEMENT: This may consist of concrete filled fabriform mats placed on slopes. Concrete is injected in a rubber "mattress" placed over the area to be protected. It may be used above and/or below the water.

GRASS, TREES AND SHRUBS: This type of protection may be utilized in relatively flat areas to prevent wind or rain caused erosion or similarly on relatively flat slopes. The application may require a layer of topsoil or fertilization and chemical treatment of existing soils to provide nutrients for this cover.

Typical sections of the above described methods of slope protection are presented in Figure IV-3.

2. CHEMICAL STABILIZATION

Chemical stabilization is the newest approach to the management of large quantities of contaminated materials. It is a most promising concept for in-situ stabilization of sediment. Most of the techniques, however, are less developed than physical stabilization methods.

There are a multitude of chemical stabilization agents (see Tables IV-3, IV-4, IV-5); but their stabilizing effects are greatly influenced by the chemical and mineralogical properties of the soils to be treated, by the types and properties of the pollutants to be contained, and by the physical and environmental conditions of treatment. There exists no single, effective stabilizing agent, i.e., no one agent is suitable for all kinds of soil, all types of environments, and all conditions of treatment. In practice, any type of stabilizing agent should be thoroughly tested for the particular soil, site, and waste to be stabilized. The best agent should be selected for each particular case. Chemical

stabilization techniques may also include physical (layering) and/or biological (vegetation) features to ensure stable, durable and environmentally sound applications.

The principle of chemical stabilization is based on the chemical bonding of soil and stabilizing agent and the immobilization of the contaminants within the stabilized mass. Under certain conditions, soil permeability may be reduced by the application of various chemicals. Or, the chemical identity of the pollutant is altered rendering the contaminant into a non-toxic substance.

Technically and economically it is only feasible, at least presently, to treat surficial layers of large deposits creating a sealing surface or barrier, similar to the installation of physical stabilization systems. Chemical sealing agents react with soil constituents to form a more impermeable membrane or layer, up to a few feet thick. Tests should be performed on each type of soil to determine the seepage rates of specific applications.

Chemically stabilized systems should be:

- (a) non-toxic to humans, animals and crops.
- (b) able to reduce seepage and infiltration significantly.
- (c) capable of non-restrictive application under a broad range of soil compositions in static or dynamic flow conditions.
- (d) able to resist damage by animals, equipment, erosion, and hydraulic (gas) pressures (20 psi).
- (e) durable and resistant to deterioration by climatic conditions such as freezing and thawing, sunlight, wetting and drying, soil micro-organisms, re-emulsification or chemical change, and reserve hydraulic flow.

- (f) capable of resealing
- (g) efficient in the use of material (low cost)

The technique of application of the chemical agent and the procedure of installation of the stabilization system is of crucial importance to the success of a sediment management program. Site conditions may require the development of a specific technique.

In the following, different classes of chemical agents are described and evaluated according to their applicability. It should be noted here that many of the chemicals and/or techniques of application are similar to those used for the fixation of dredge spoil. The four different categories of chemicals are:

- (1) Lime and its Variations
- (2) Cement and its Variations
- (3) Asphalt and other Soil Sealants
- (4) Sorbents and other Additives

1. LIME AND ITS VARIATIONS

It has long been recognized that Lime (calcium oxide, hydroxide or dolomitic lime) has a high potential for physical and chemical amelioration of natural soils. Added in relatively small amounts lime or one of its variations is able to achieve many beneficial effects. In addition to increasing the compressibility of the soil (bearing strata for foundations) it alters the chemical composition of the soil. Thanks to the latter feature, lime was discovered as a chemical agent for waste stabilization.

Limes reportedly have been applied as chemical agents in many variations, especially in Japan (see Table IV-3). Lime is mixed into clayey and fine granular soils for its effects as a flocculant or base exchanger. Its addition raises the pH of a soil considerably. This increases the sorption capacity of the soil and, hence, the ability of

the soil to chemically bind many of the occurring ionic contaminants. Lime also dewateres the soil, thus, reducing the leachability of the contaminated material. Finally, it promotes some pozzolonic reaction strengthening the soil matrix for physical loading.

Lime can be applied in solid (powder) or liquid (slurry) form. Depending on the type of soil and the type of lime (see Table IV-3), the agent may be added at rates between 2 and 10 percent. For many soils about 5% is optimum for effecting ion exchange and cementation.

Traditional soil blending techniques may be applied to mix the agent into the surface layer of the deposits to be stabilized. Mixing and incorporating can be accomplished with rotary hoes, tillers, back hoes, harrows or other agricultural equipment. Water should be added in the desired amount; then, within one hour the surface should be compacted. Sprinkling intermittently helps during a curing period of several days. The last step may be combined with placing a layer of topsoil and with preparation and seeding for vegetation.

Recently deep-lime-mixing techniques were developed in Japan and have been used for stabilization of in-situ soft clayey layers in both aquatic and terrestrial projects. High activity quicklime was used because of its quick hydration and ease of mixing.

A method for driving of lime piles (columns) was developed by the Swedish Geotechnical Institute and the Royal University of Technology in Stockholm. Although developed for geotechnical purposes (improvement of bearing capacity), it is readily adaptable for chemical stabilization purposes.

Lime columns are constructed in place by mixing the soil with finely pulverized quick lime (or any other suitable stabilizing agent!) as illustrated in Figure IV-4.

Rotational speed of max.
auger mixer.
Feed rate down: up: 25
Boring angles max. 10° (in all d
Storage container volume 2.5 m³

Weight:
Total weight (transport weight) ... approx.
Total weight (fully loaded) approx.
Ground pressure approx.

Dimensions:
Mast transport position
Length 12.5 m
Height 3.6 m
Width 2.5 m

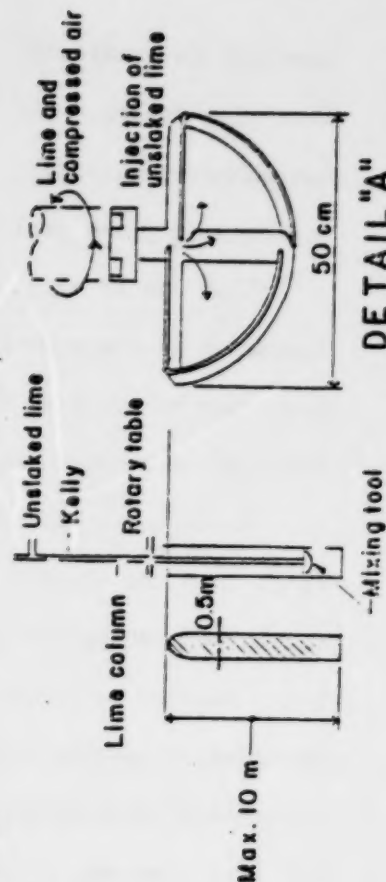
See DET. "A"

Total weight (transport weight) approx. 10 tons
Total weight (fully loaded) approx. 12.5 tons
Ground pressure approx. 0.024 MPa

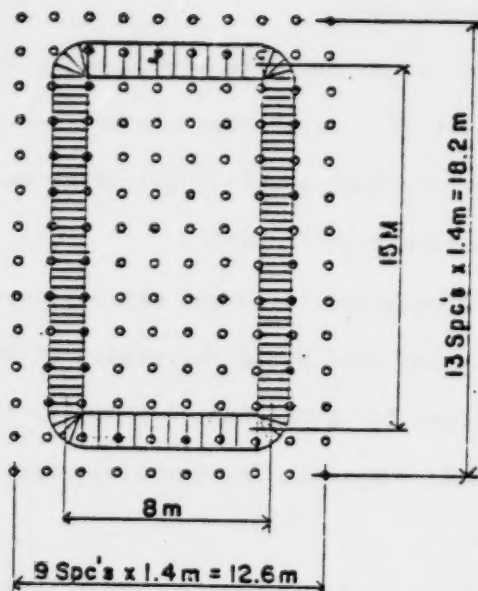
Moat transport position	
Length	12.5 m
Height	3.6 m
Width	2.5 m

See DET "A"

ELEVATION EQUIPMENT



PLAN-TYPICAL LIME COLUMN LAYOUT



REPORT ON BLACKSTONE RIVER SEDIMENT CONTROL AND REMOVAL

FIGURE IV-4

A mixing tool with 0.5m diameter at the end of a long rod is screwed down into the soil to the desired length of the column, maximum 10m or 33 ft. At the bottom the direction of the rotation is reversed, and the tool is slowly pulled out. The stabilizing agent is pressed out with compressed air from the tool head when it is slowly drawn up. The downgoing speed could be up to 100mm per revolution, max. 75r/m, but the upgoing speed is less, max. 25mm per revolution in order to give a good mixing of agent and soil. Since the blades are slightly inclined, there is some compaction effect. The equipment (see Figure IV-4) comprises a mast with the drilling tool and rod and motors for the operation, a trailer with hydraulic drive, and a pressure tank for the chemical agent. The mast can be collapsed during transportation.

By means of its hydraulic system the equipment can be adjusted on the ground to ensure that the mast and the downward movement of the rod are truly vertical. This is checked on a special instrument by the operator. The amount of chemical agent blown into the soil is also checked during the operation to ensure a uniform application. The equipment weighs 22 tons and has a ground pressure of only 25kPa (0.25kp/cm^2).

The maximum capacity is about 300m column in 8 hours. Figure IV-4 shows the 3rd generation developed by Linden-Alimak, Inc. a producer of building equipment.

It may be noted that the installation of lime slurry walls, or bentonite walls, constructed in the usual fashion appears to be a technically feasible method to physically and chemically stabilize a contaminated site. A vertical wall would simply embrace the site and represent an impermeable barrier to leachate movement. This concept may be applicable where exposed contaminated deposits are located adjacent

to surface or groundwater bodies.

Several variations of lime can be used for lime stabilization:

Quicklime - is one of the most popular and widely used agents in road construction for subbase and subgrade stabilization. It is particularly effective because of its quick hydration and ease of mixing.

Chemico Lime -100 - is quicklime with some additives and is produced in Japan. It is used for both road construction as Chemico Lizer and for deep stabilization by means of lime piles as Chemico Pile. Semmi Lime consists mainly of quicklime and is also used for road construction or as lime piles. Hydrated lime is used as widely for road construction as quicklime. It is possible to use it in the form of slurry for deep mixing stabilization. Road lime consists mainly of hydrated lime with a small amount of water. It is used for road construction too.

Slag (blast furnace slag) or fly ash is not very effective in the pure state for rapid soil stabilization. But with the aid of quick hydrated lime, or cement, its reactivity becomes greater and more rapid. It is attractive as an additive to soil because of its pozzolonic properties, i.e., although not a cement itself fly ash develops cementitious properties with lime or cement and water.

Other slag-lime mixtures include slag bacillus which consists mainly of slag and contains gypsum, hydrated lime and other materials. Gypsum itself, mixed with lime, may also prove to be a usable agent.

Finally, Hi-Tog, a Japanese product, is sludge ash from sewage with some hydrated lime. It allows reuse of a waste product and, in some instances, may be a useful material.

Proportioning of oil, lime, and fly ash is dictated by economy and desired properties in normal soil stabilization. Fly ash usually is abundantly available. This may lead to the practice of using as much fly ash as can be tolerated. Hence, a mix for chemical stabilization may contain between 20% and 60% fly ash, 5% lime, and the rest soil.

Laboratory tests or field trials will be necessary to establish the best types of ingredients, optimum mixing ratios and depths of stabilization. It should be noted, however, that application of fly ash (slag) may not be environmentally sound as it contains considerable amounts of (heavy) metals.

2. CEMENT AND ITS VARIATIONS

Much of the same description as presented above for lime, holds for cement (Portland cement) which is also a chemical agent with dewatering, solidifying and base exchange effects (see Table IV-3).

Portland cement has been widely used in road construction in the form of soil-cement. Recently it has been used in Japan for solidifying soft dredged soils and also has been tried mixed with deep in-situ clayey soils as Deep Chemical Mixing Method or DCMM, i.e. soil cement applied in slurry form.

Soil cement is composed of sandy soil or material encountered on site, portland cement, and water that have reacted and hardened. About 8% of dry cement is incorporated in place (rotary hoe, etc.) and compacted (sheepsfoot roller) after water is added to about optimum content. Premixing and placement wet is another method, similar to admixed lining, that seems less amenable to covering waste, however, because of extra cost. Somewhat higher cement content is needed in poorly graded soils or where fines are lacking, but correspondingly less for well-graded mixtures.

In the presence of fine-grained soils, soil cements with permeability coefficients of about $k=10^{-6}$ cm/sec can be obtained. This is comparable to a highly impermeable clay. In actual practice, surface sealants are occasionally applied to soil cement systems to obtain an even more waterproof structure.

Aging and weathering characteristics of soil cement systems are fairly good, especially those associated with the wet-dry and freeze-thaw cycles. Some degradation of soil cement matrices can be expected in an acidic environment, however.

In some cases, cement mortar, a slurry of cement and sand, is a more effective stabilizer than soil cement. Fuji-Benton is a mix that consists of portland cement and various additives, organic and/or inorganic. It has widely been used in Japan for sludge treatment and surface stabilization of reclaimed land. Fudi Mix is another type of portland cement blended with various additives, used for surface treatment as the Consolider System.

Chemico Lime-200 and -400 are portland cement with some amount of hydrated lime. They are in liquid form for surface treatment as the mini-max method or M.R. method, and as the Mixer method in solid form. Slag cement is, in some cases, more effective and economical than portland cement. It is also widely used in surface and deep stabilizations, similar to lime. .

3. ASPHALTS AND OTHER SOIL SEALANTS

Numerous bituminous materials have been successfully (re)used as chemical stabilizaton agents. Tables IV-3, IV-4, and IV-5 give an extensive listing of all those materials. Since the stabilizing effects of these agents are physical as well as chemical, some of them have been introduced earlier already in context with admixed materials. Also,

bituminous materials are used as agents for dredge spoil fixation.

Soil-Bitumen, similar to soil-cement or lime-treated soil, stabilizes sandy soils by cementing or waterproofing. An optimum content of bitumen increases the cohesion of the soil, yet does not separate grains enough to reduce frictional strength. From 4% to 8% bitumen (soil dry weight basis) is recommended as a first cut for sandy loam to be refined subsequently by testing mixtures of various contents. Sand should require somewhat less bitumen.

The mixing procedure should be developed site-specifically (as for limes and cements). Water is added as needed to the soil for desired compaction, then cutback or emulsified asphalt or tar. Further mixing, spreading and compacting should be accomplished in relatively short time. It may be expeditious to spread before adding the bitumen. The critical time from final mixing to compaction is thereby reduced to as little as a few minutes.

The longevity of effectiveness of soil-bitumen is a factor that deserves careful consideration. Volatiles eventually leak away and leave the system in an altered, sometimes degraded condition. Cracking will also reduce integrity. Covering of the stabilized surface layer may largely reduce these adverse effects.

Some inorganic agents like sodium compounds, (see Tables IV-4, IV-5) have been used as stabilizing agents. These soluble salts act as dispersing agents and are recommended for improving soil compaction and reducing the hydraulic permeability. The treatment is primarily for fine-grained soils containing clay minerals.

Dispersion (deflocculation) involves the breakdown of clayey aggregates into the individual mineral particles. The effect is to increase dry

weight (dewatering) to lower permeability, and to facilitate compaction. Testing should be undertaken prior to the use of such dispersants. It is obvious that application of these dispersants alone will not create a satisfactory stabilization system. Their use is recommended, however, in combination with layering of natural soils or other physical lining methods.

4. SORBENTS AND OTHER ADDITIVES

Hundreds of other chemicals have been proposed for their beneficial effects on soils (see Table IV-5). Some are reported to impact water repellency and strength; some affect the sorption capacity of the soil; others have more obscure attributes. Many of these compounds are proprietary development (chemical industry) and their properties and characteristics are difficult to evaluate.

Some previous experience or assistance from authoritative sources will often be necessary for the designer to make a choice among these products; thorough testing is indispensable. The following criteria should be considered in selecting an additive: cost, ease of application, and duration of effectiveness. Many additives work for only a short period, so that rapid follow-up treatment, such as covering of the treated surface or establishment of vegetation, will usually be necessary to sustain the benefits. Some of these chemicals may be effective under water also if applied by injection or other method.

Natural sorbents, such as activated carbon, and synthetic sorbents, such as resinous and polymeric materials have been shown to be effective in stabilizing contaminated sediments and waste impoundment sites. In application, sorbents act much like natural sediments do in maintaining levels of contaminants for higher than those in adjacent areas.

Sorbents having lower partition values (concentration in water/ concentration in treated soil) than those exhibited in natural sediments will reduce the levels of easily dissolvable pollutants in the sediments (and the levels of dissolved contaminants in the interstitial water). A three-phase equilibrium is established with the highest concentration of pollutants adsorbed on the sorbents, lower concentration on the soil material, and the lowest concentration in the interstitial water.

Some of the sorbents have been proposed for under water application. Activated carbon, for instance, upon spreading across the water surface, will settle to the ground and set up a layer of strongly sorptive material that filters leachate from the sediments. To protect that filter it should be covered with layers of well graded granular material (sand, gravel). However, this concept of under water chemical stabilization of contaminated sediments has not been tested yet. It might be a rather expensive undertaking if the site to be treated is large.

Polymeric (resinous) compounds have been developed which appear promising for use as chemical stabilization agents. They lend themselves to both above water (spraying, injecting, mixing) and under water application (injection). They were originally used for fixation of toxic dredge spoil, however.

Most of these polymeric compounds (synthetic resins) consist of a blend of a high-molecular-weight linear polymer and a crosslinked, swellable polymer. The linear polymer's sorptive sites allow it to sorb to the soil and form a flexible network. The cross-linked polymer is extrudable and can infiltrate the permeability channels of a soil, thus, sealing the solidified matrix.

When used for exposed deposits, the polymer is mixed in a low pH water/acid solution and then sprayed on the earthen surface as a low viscosity slurry. The low pH condition allows the polymer to penetrate the surface. Upon wetting of the soil the water swellable portion of the resin swells and becomes locked in place. The linear polymer attaches to the soil and also immobilizes the contaminants.

Another formulation that has been successfully used is a bentonite/polymer system in which bentonite replaces the cross-linked polymer portion. This mix is not as efficient as the above, but it is considerably cheaper. It can be applied by dry blending (see techniques mentioned before), spraying, injection, deep incorporation (see lime piles), etc. One of the most crucial factors that affect the efficiency of polymeric sealants is the method of application. Hence, tests and pilot studies are strongly recommended.

It should be noted that many of those chemicals may have adverse impacts on the environment of the site of application. Table IV-5 contains a brief description of a large number of these chemicals. Major properties and characteristics of the compounds are listed as well.

3. BIOLOGICAL STABILIZATION

Besides the categories of physical and chemical techniques, a third type of in-situ stabilization method can be distinguished, namely biological stabilization. The concept of biological stabilization is based on the potential of living organisms to physically remove (uptake) or chemically alter inorganic and organic substances (pollutants).

The concept has been applied successfully in the field of sanitary engineering (wastewater treatment), where micro-organisms are used to convert the colloidal and dissolved carbonaceous organic matter into various gases and into settleable tissue. As to the application of the

TABLE IV-3
CHEMICAL STABILIZING AGENTS USED ON RECLAIMED SURFACE AND IN-SITU SOFT SOIL

Type	Main Component	Name of Agent	Phase in Use	Method of Treatment	Name of Treatment
Lime	Quicklime	Quicklime	solid	mixing (deep/shallow)	Deep-Lime-Mixing, etc.
		Chemco Lime -100	solid	mixing (shallow)	Chemco Lizer
				lime pile	Chemco Pile
Lime	hydrated lime	Sent Lime	solid	mixing/lime pile	
		Hydrated Lime	solid/slurry	mixing (shallow/deep)	
	slag with lime	Road Lime	solid	mixing	Solid Liner
		Slag with Lime	solid	mixing	
		Slag Bacillus	solid	mixing	slag, gypsum and hydrated lime
Cement	gypsum and lime ash/hydrated lime	Gypsum with Lime III-Tog	solid	mixing	
			solid	mixing	
		Portland Cement	slurry/solid	mixing (deep/shallow)	
	Portland Cement	Cement Mortar	slurry	mixing (deep)	Deep Chemical Mixing, etc.
		Fuji Beton-FPC	slurry	mixing (shallow)	Clay Mixing Consolidation
		Fuji Beton Toa -PC, -FK, -Al	slurry	mixing (shallow)	IDS Method
		Fudo Mix	slurry	mixing (shallow)	Consolider System
			slurry	sludge mixing	TST System
	Portland Cement and hydrated lime	Chemco Lime -200, -400	slurry	mixing (shallow)	Mini-max, M.R.
	Portland Cement and slag	Slag Cement	solid	mixing (shallow)	Mixer
			slurry	mixing (shallow/deep)	

TABLE IV-3 (CONT'D)

Type	Main Component	Name of Agent	Phase in Use	Method of Treatment	Name of Treatment
Asphalt		Dunks HS-1, 2		mixing with soil with cement, for rapid solidification	
		Nisso ALM EB-CX		ditto, for lig fixing ditto, for fixing metallic compounds	
Additives	polymer	Danseal X5		ditto, for making impervious film	
		Konseal		ditto, for organic soils	

Source: LPA-600/3-77-003 "Management of Bottom Sediments Containing Toxic Substances," July 1977

TABLE IV-4
REPRESENTATIVE SOIL SEALANTS AND DISPERSANTS

<u>Sealant</u>	<u>Application</u>	<u>Remarks</u>
Oil-soluble polymers in diesel fuel	Fresh Water	Injected beneath surfaces of water where seepage was occurring.
Sodium tetraphosphate	Sulfite liquor storage	Dispersant distributed in 15.2 cm (6 in) layer of soil at 2.3 kg/9 m ² (5 lb/100 ft ²). Careful compaction rendered soil impervious.
Sodium carbonate	Canals	Wet-dry cycles disrupt water barrier. Used 183 g (0.4 lb) of reagent/0.84 m ² (yd ²) of soil.
Lignin derivatives gelled alum	Desalination by-product brine	1% lignin cost \$3,400/4,047 m ² (acre).
Carboxymethyl-cellulose with alum	Desalination by-product brine	0.2% carboxymethylcellulose cost \$2,250/4,047 m ² (acre).
Petroleum emulsions	Desalination by-product brine	4% additive cost \$4,400/4,047 m ² (acre).
Attapulgite clay	Desalination by-product brine	2% Zeogel cost \$1,000/4,047 m ² (acre).

Source: EPA-600/12-78-196

TABLE IV-5 (CONTINUED)
.... Attribute

Category and Agent	Strength	Water	Dust/ Wind	Comments**
Soil Seal	---	---	yes	Emulsion of material copolymers in the plastic resin range. Effective in fine-grained sand.
Vinsol	---	yes	---	Powdered resinous substance. Effective in sandy silt, silty sand, clayey silt, and clayey sand. Susceptible to microbial attack.
Vistron Silmar S-3840	yes	---	---	Modified polyester resin. Requires moisture to cure. Causes low strength gains.
Whitesides 69-Y-1	yes	---	---	Emulsified epoxy resin. Effective mixed with clay.
<u>Polymeric materials</u> Compound SP 301	---	yes	---	Latex copolymer emulsion. Effective in spray application.
Curasol AE	---	---	yes	Polyvinyl acetate latex dispersion. Forms a hard crust. Cleanup is difficult.
Curasol AH	---	---	yes	Polyvinyl acetate latex. Forms a flexible crust.
Neopreen 750	yes	---	yes	
Petroset AX	yes	yes	yes	Emulsion of elastomer, asphalt, solvents and water.
Petroset AT	yes	yes	yes	Emulsion of elastomer oils and water.
Polyco 2460	---	yes	---	Styrene/butadiene latex. Effective in spray applications.
Surfaseal	---	---	yes	Viscous plastic material. May require several applications, allowing drying time prior to each additional application.
Terra-krete	---	---	yes	Chemicals in latex base. Forms hard surface.
Ucar 130	---	---	yes	Polyvinyl acetate.
Vultex 1-V-10	---	---	yes	Prevulcanized rubber latex.
White soil stabilizer	---	yes	---	Latex polymer, effective mixed with soil.
<u>Bituminous materials</u> APSS (asphalt penetrative soil binder)	---	---	yes	Low penetration grade asphalt, kerosene and naphtha. Good penetration in impervious or tight soils.
Liquid shale tar (shale oil) yes		---	---	Cures in 6-12 hr. Flammable. Effective in sand or clay.

TABLE IV-5 (CONTINUED)

Category and Agent	Attribute....			Comments**
	Strength	Water	Dust/ Wind	
Emion E-200	yes	yes	yes	Water-soluble resin that cures within 2 hr in combination with diethylene triamine. Effective in sand or clay.
Epon 828	---	yes	yes	Epoxy resin with slow curing time. Penetrates sand or clay and forms a hard crust.
Epon 828+V40	yes	---	---	Blend of Epon 828 and V40. Effective in sand or clay.
General latex-Vultex	yes	---	---	Blend of epoxy and a catalyst. Causes low strength gain.
General Mills TSX-429+TSX-428	yes	---	---	Blend of a resin and a coreactive resin. Causes low strength gain.
HK-1	---	---	yes	1:1 mix of Base 792-D and 792-L.
HK-2	yes	---	yes	3:1 mix of Base 792-D and 792-L. Forms tough resilient film but curing can take more than 7 hr with loose sand in humid conditions.
Jones-Dabney No. 6	yes	---	---	Blend of EpiRez S159, S044 and EpiCure 874. Effective in sand or clay. —
Jones-Dabney No. 7	yes	---	---	—
Lignin liquor	---	---	yes	Resinous alkali waste and compounds.
Ligno sulfonates	yes	yes	yes	See Norlig 41.
Lino-cure C	---	yes	---	Foundry resin that forms a hard waterproof surface when applied with ethylene glycol.
Norlig 41	yes	yes	yes	Ligno sulfonate.
Orzan	yes	yes	yes	Mixture of ligno sulfonate and chemicals. Forms shrinkage cracks when cured. May be leached out by water.
Paracol TC1842	---	---	yes	Resin emulsion. Good results with mine tailings.
Paracol S1461	---	---	yes	Blend of wax and resin. Effective with mine tailings.
Petroset R5	yes	yes	yes	Emulsion of resins, elastomer and volatile solvents.
Petroset S8	yes	yes	yes	Effective in gravel and rock. Emulsion of resins, elastomer oils, solvents and water. Effective in particles below gravel size.
R 20	---	yes	---	Sodium methyl silanolate. Non-biodegradable.
Resinoz 9673	---	yes	---	—
Resin 321	---	yes	---	Finely powdered resinous substance. Effective in acid soils (silty clay and clayey silt).

TABLE IV-5(CONTINUED)

Category and Agent	Attribute....			Comments**
	Strength	Water	Dust/ Wind	
Ashland CR 726	yes	---	---	Blend of resorcinol and an accelerator. Effective mixed with clay.
Base 792-D	---	---	yes	Blend of polyvinyl resins and modifiers.
Base 792-L	---	---	yes	Similar to Base 792-D.
Celanese 13-67-5	yes	---	---	
Celanese 510+872	yes	---	---	Blend of EpiRez 510 and EpiCure 372. Effective mixed with sand.
Celanese 16-78-16	yes	---	---	Blend of EpiRez 510, 544, and EpiCure 8701. Requires moisture to cure. Effective mixed with sand.
Celanese 16-78-1	yes	---	---	Blend of EpiRez 510, 356, and EpiCure 37. Effective mixed with sand or clay.
Celanese 16-77-1	yes	---	---	
Chem-Rez 200	---	---	yes	Furfural based rapid setting resin. Effective in sand or clay.
Chrome lignin	---	yes	---	Resinous alkali waste and a hexavalent chromium compound in gel form.
Ciba 509+8157/136	yes	---	---	Blend of Araldite 509 and X8157/136. Effective mixed with clay.
Ciba 6010+X8157/136	yes	---	---	Blend of Araldite 6010 and X8157/136. Effective with sand or clay of variable moisture content.
Ciba 6010+8157/137	yes	---	---	
DCA-70	yes	---	yes	Emulsion of polyvinyl acetate and chemical modifiers. Cures in 2 to 4 hours. Can be reinforced with fiber glass filaments.
DCA-1295	yes	---	yes	Improved DCA-70. Fiber glass reinforcement may be harmful if inhaled or blown into eyes.
Dow CX-7	yes	---	---	Blend of vinyl ester resin, benzoyl peroxide, and N, N-dimethylaniline. Fast curing. Effective mixed with sand.
Dow Derakene 114	yes	---	---	Blend of vinyl ester resin, benzoyl peroxide, and N, N-dimethylaniline. Requires moisture to cure. Effective mixed with sand or clay.
Dresinate DS-60W-80F	---	yes	---	Thermoplastic resin. Effective in spray applications.
Edoco X-2111-1	yes	---	---	Effective in sand or clay.

TABLE IV-5
CHEMICAL ADDITIVES FOR STABILIZATION OF SOIL

....Attribute*....

Category and Agent	Strength	Water	Dust/ Wind	Comments
<u>Inorganic Chemicals</u>				
Calcium chloride	yes	yes	yes	Maintains moisture content. Easily leached out by water.
Lime	yes	—	—	See discussion in text, Table V-1
Cement	yes	—	—	—
Phosphoric acid	yes	—	—	Cementing agent. Mixes easily with soil.
Potassium silicate	—	—	yes	—
Sodium carbonate	—	—	—	See Table V-2
Sodium chloride	yes	—	—	Easily leached out by water.
Sodium silicate	—	—	yes	Effective in well-graded, compacted sand.
Soil Lok	—	—	yes	Combination sodium silicate and calcium chloride. Effective in fine-graded soils. Forms hard surface.
<u>Resinous materials</u>				
Aerospray 52	—	yes	—	Alkyd resin emulsion that forms a hard crust.
Aerospray 70	—	yes	—	Polyvinyl acetate resin emulsion. Effective in sand.
AM-9	yes	—	yes	Blend of water-soluble acrylamide and diacrylamide. Provides flexible surface after long curing.
Amoco A	yes	—	—	Requires moisture and temperature above 40°F (4° C) to cure. Effective mixed with sand.
Amoco 3	yes	—	—	Fast curing resin. Effective mixed with sand.
Aniline - furfural	yes	yes	yes	Provides tough surface for dry silt and clay. Soil moisture reduces final strength. Toxic.
Aniline hydrochloride furfural	yes	—	—	Nontoxic resin. Effective in highly acid or neutral soils with plasticity index (PI) of 3 to 20.
Aroplaz 6065	—	yes	—	—
Aropol 7110	yes	—	yes	Unsaturated polyester resin. Significantly increases soil strength of sand, silt, or clay.
Aropol 7720 M	—	—	yes	unsaturated polyester resin. Effective in sand, silt, or clay.
Arothane 156	—	yes	—	Polyurethane elastomer with rapid curing.
Arothane 160	yes	yes	yes	Polyurethane elastomer with rapid curing. Effective in clay.
Arothane 170	yes	yes	yes	Similar to Arothane 160.

TABLE IV-5 (CONTINUED)

....Attribute*....

Category and Agent	Strength	Water	Dust/ Wind	Comments**
<u>Miscellaneous materials</u>				
Admex 710	---	---	yes	-----
Aggrecote 600	---	---	yes	-----
Aquatin	---	yes	---	Concentrate of chemicals and pectin. Forms fragile crust. Stains skin, clothing and equipment.
Bio-binder	---	yes	---	For spray applications.
Bisphenol A	---	---	yes	-----
Calcium acrylate	yes	yes	---	Organic salt that forms strong bonds in wet, fine-grained soils.
Calcium sulfonate	---	yes	---	-----
Cyanaloc 62	---	yes	yes	-----
Dust bond 100	---	yes	---	-----
Dustrol	---	yes	yes	Medium grade road oil. Flammable.
Formula 125	---	yes	---	Organic cementing agent and a sodium methyl siliconate base. Effective in gravel to clay. Caustic in concentrated form.
Gelatin 15XPF	---	yes	---	Good penetration in sand. Forms hard, brittle surface.
Goodyear K335	---	---	yes	-----
Heavetex P1396	yes	---	---	-----
Heavetex P1397	yes	---	---	-----
Hysol	yes	---	---	-----
K-aton 101	---	---	yes	-----
Landlock	---	---	yes	-----
Lemac 40	---	---	yes	-----
Orzan GL-50	---	yes	---	Cementing material that can be sprayed or mixed with soil.
Pacific N 748 N	yes	---	yes	-----
Stabinol	---	yes	---	3:1 mix of Portland cement and Resin 321 or a complex salt. Deteriorates after long storage.
Sulfite liquor	yes	---	---	Effective sprayed on sand and gravel. Easily leached out by water.
Terra-krete No. 2	---	yes	---	Inorganic and organic materials with a synthetic binder.
Tung oil	---	yes	---	-----
Waste oil	yes	yes	yes	-----

*Attributes are marked yes where addition to soil is claimed (not necessarily substantiated) to stabilize generally, to repel water or resist water erosion, or to resist dusting or wind erosion. Dispersants are another group of additives used primarily to aid in the compacting process; they are not included in this table but are discussed in the text.

**The pollution potential of additives should be given special consideration prior to usage.

Source: EPA-600/2-79-165

concept to contaminated sediments, or any waste deposits, biological stabilization was found in the literature to be discussed strictly on a level of basic and applied research. There are no conclusive data available yet.

The concept of biological stabilization can be divided into two intrinsically different techniques:

- (1) Bio-Harvesting
- (2) Bio-Degradation

In the following, a brief description and evaluation of the characteristics of each technique is presented.

1. BIO-HARVESTING

The technique of bio-harvesting utilizes the phenomenon of bio-magnification (or bio-concentration) of chemical substances in living organisms. All of the organisms which constitute a so-called food chain incorporate, absorb, ingest, or inhale organic and inorganic substances that occur in some form or other in their aquatic and/or terrestrial habitats.

Some of these organisms are known for their high rate of bio-concentration of certain chemicals which are toxic to the environment. It is the intent of the concept of bio-harvesting to use those organisms as biological agents for the removal of in-place pollutants. Periodic harvesting of sufficient quantities of polluted organisms in addition to replenishment of the site with equal quantities of clean organisms is believed to gradually and systematically purify the site.

Both exposed and submerged deposits can possibly be treated biologically. Suitable organisms theoretically include plants and animals. Certain fast growing plants could be selected, or bio-engineered,

which allow high rate accumulation of in-place pollutants without inhibition of growth. Those plants should lend themselves to an economic way of seeding and harvesting.

It has also been proposed to use some species of fish, instead of or in addition to plants, which share similar capabilities of bio-magnifying ambient levels of contaminants. While plants would be able to extract the contaminants directly from the deposits, fish would depend on food chain mechanisms and high rates of leachate from the sediments into the water body.

Upon harvesting of the "loaded" organisms, disposal in an environmentally safe manner should be secured. Incineration or anaerobic digestion are options which might even be economically beneficial, e.g., production of methane gas, reuse of ash as fertilizer, etc., might be possible.

One must keep in mind, however, that the concept of bio-harvesting presently is more of a scientific and engineering vision than a tested and reliable method of in-situ stabilization.

2. BIO-DEGRADATION

The method of bio-degradation has been proposed for the purpose of purification of contaminated soils. Some feasibility studies have been conducted regarding the potential of bio-degradation for dredge spoil fixation. Results of those studies or data in any form have not been reported. No known attempts have been undertaken as yet to investigate the applicability of this concept to in-situ stabilization of contaminated sediments or hazardous wastes.

The concept of bio-degradation is based on the fact that some micro-organisms have the capability of metabolic degradation of certain

chemical compounds which, due to their synthetic nature or high concentration, are hazardous to the environment. Recent developments in the field of genetic engineering suggest that it may soon be possible to produce strains of micro-organisms which are genetically designed such that their metabolism is capable of degrading specific contaminants.

The concept of bio-degradation appears to be most promising with regard to application to organic pollutants such as pesticides, PCB's, etc. Also, some (heavy) metals may occur in synthetic toxic organic compounds, which are degradable into non-toxic inorganic compounds. Yet most metallic compounds are not degradable.

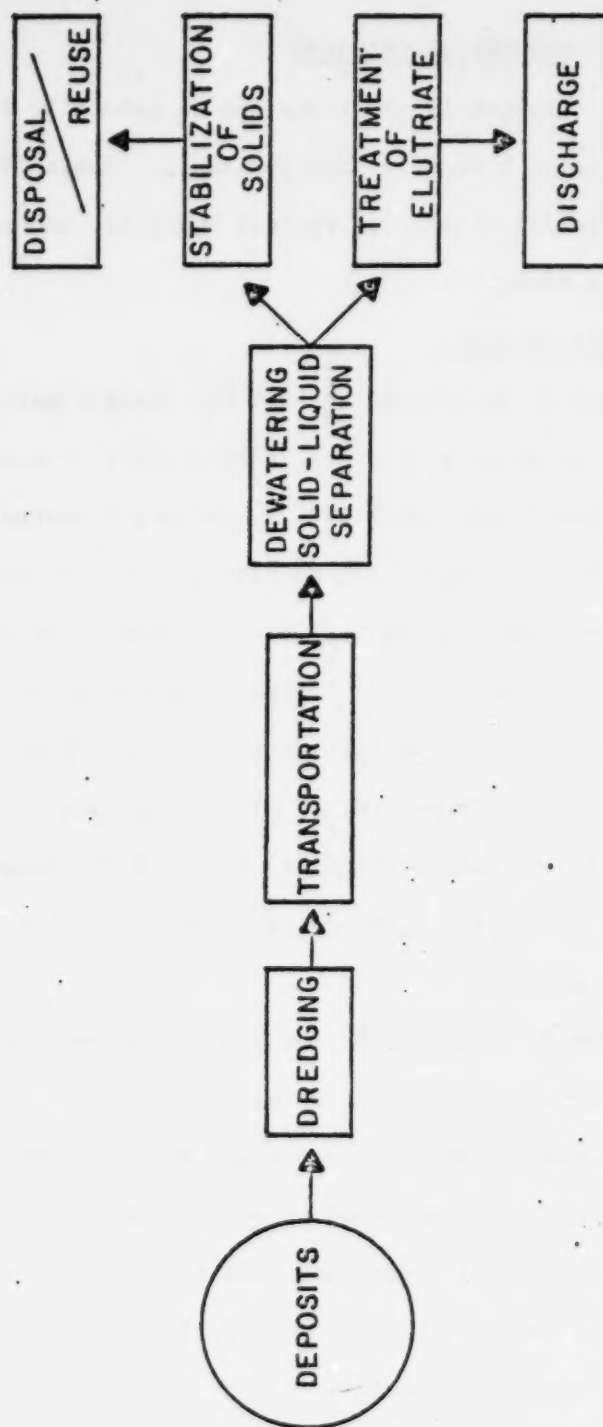
It must be recognized, however, that at the present state of development bio-degradation of in-place pollutants is not feasible.

4. DREDGING OF SEDIMENTS

A. GENERAL

One of the most important considerations in designing a dredging operation is to prevent the dispersion of toxic substances into the environment in the course of dredging, treating and disposing of deposits. If the dredging operation is performed without sufficient understanding of the behavior of these toxic substances, assuming the dredge spoils contain contaminants and without avoiding dispersion of them into the environment, the possibility exists that the efforts to control pollution could, instead, turn into initiation of secondary environmental pollution.

The methods of dredging, treating and disposing of contaminated materials may differ depending upon the characteristics of the deposits to be handled and the geographic and social conditions of the area where the deposition took place. However, a general flow diagram for a dredging operation may be expressed as shown in Figure IV-5.



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FIGURE IV-5

SCHEMATIC FLOW DIAGRAM
OF DREDGING PROGRAM

B. METHODS OF DREDGING

Dredges in use today can be generally divided into three categories; mechanical, hydraulic, and pneumatic. Table IV-6 presents a brief summary of specifications for typical hydraulic and one pneumatic dredges for various tasks.

1. MECHANICAL DREDGES

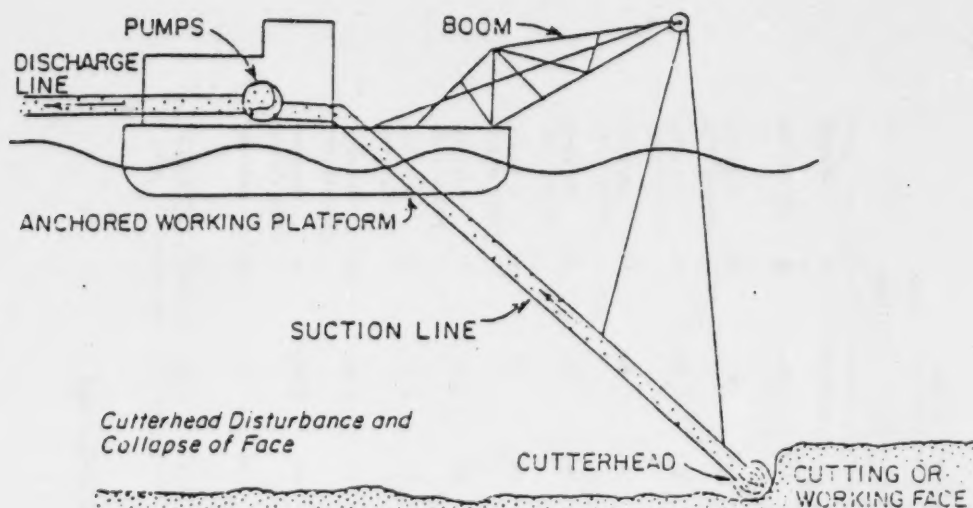
Mechanical dredges normally lift the dredged material above the waterline by means of buckets, dippers, clam shells, or scoops (see Figure IV-6). They then deposit the dredge spoil into a conveyance system for transport from the dredge site. These dredges need no dilution and can operate both in water and on land. Often, considerable turbidity is created at the dredge site during operations of these types of dredges. Secondary pollution may be induced during conveyance due to high water content (if dredged in water body) in the dredged material. Consequently, without the use of sediment control measures such as silt curtains, turbidity barriers or "diapers," mechanical dredges may pose a threat for aggravating an existing, but possibly dormant, in-place pollution problem.

Elutriate tests as developed by the U.S. Corps of Engineers may assist in an evaluation of different dredging methods.

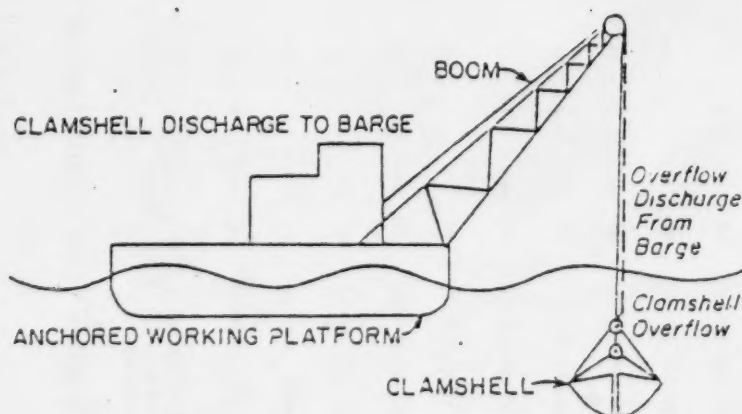
Dredging of contaminated materials which are not submerged in still or flowing waters can be accomplished by any conventional mechanical means. Ample experience and literature exists as to how to employ bulldozers, crawlers, scrapers, etc. Secondary pollution other than dust development is not expected to occur.

2. HYDRAULIC DREDGES

Hydraulic dredges generally move bottom material via a centrifugal pump and pipeline. In the United States hydraulic dredges are most



HYDRAULIC CUTTERHEAD DREDGE



MECHANICAL CLAMSHELL DREDGE

SOURCE: E.P.A.-600/3-79-102
 "Management of Bottom Sediments
 Containing Toxic Substances"

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FIGURE IV-6

**MOST COMMON DREDGING METHODS
 FOR BOTTOM SEDIMENTS**

TABLE IV-6

SPECIFICATIONS FOR TYPICAL HYDRAULIC AND (ONE) PNEUMATIC DREDGES OF VARIOUS TASKS

Type Dredge	Pipeline Diameter In.	Weight tons	Length Ft.	Width Ft.	Height Ft.	Draft In.	Freeboard In.	No.	Dredge Pumps HP	Production Rate cu yd/hr	Dredging Depth Ft.	Maximum Depth of Single Pass Excav. In.	Remarks
Dredge	32	---	244	50	60	60	48	1	2100	38	Steam	3500	60
Cutterhead/ Suction	6	18.5	44	11	20	34	14	1	175	8	Diesel	29-95	12
Cutterhead/ Suction	8	18.5	44	11	20	35	13	1	175	8	Diesel	45-105	12
Cutterhead/ Suction	10	72.5	90	17	33	43	17	1	335	12	Diesel	60-300	25
Cutterhead/ Suction	12	73.5	90	20	33	42	18	1	520	14	Diesel	120-540	25
Cutterhead/ Suction	14	87	95	20	33	43	17	1	520	16	Diesel	160-700	25
Cutterhead/ Suction	16	166	130	28	55	55	17	1	1125	18	Diesel	240-875	40
Cutterhead/ Suction	20	316	180	32	70	54	42	1	1700	24	Diesel	310-1365	50
Cutterhead/ Suction	24	326	185	32	70	56	40	1	2250	24	Diesel	515-1615	50
Cutterhead/ Suction	30	350	225	36	67	60	36	1	3600	30	Diesel	572-2500	50
Pneumatic	8	50	115	32	82	63	33	3	710	NA	Diesel	60-390	65
PRODUCAT	8	13.9	30	8	5	18	12	1	175	8	Diesel	60-150	15

Source: "In-Place Removal of Solid Toxics: Available Tools" by J.L. Goodwin, C.B. Thompson

Note: Production Rate shown in table is theoretical rate, i.e., based on the capacity of the equipment and does not include down time.

commonly used for maintenance and new work projects.

The hydraulic suction dredge can be fitted with various mechanisms at the suction pipe inlet which facilitate sediment removal (see Figure IV-6). These mechanisms include rotary cutters or cutterheads, auger-type cutterheads, or high pressure water jets. Hydraulic dredges can be used for both on-land and under-water operations. In case of under-water application, mud shields or dust pans are used on some hydraulic dredges in conjunction with the water jets to reduce secondary suspension at the suction inlet. However, these dredges collect only 10 to 30 percent solids, cause considerable sediment agitation when mechanical cutterheads are used and induce secondary pollution unless control measures are taken.

The low percentage of solids imposes high costs in treatment of the elutriate at the dredge spoilsite prior to return of the liquid to a receiving water. Also, high transportation costs are expected to be incurred.

Some types of hydraulic dredges in the United States include the cutterhead, the plain suction, the dust pan, the hopper, the side caster, and the Mud Cat.

The utilization of hydraulic dredging (Figure IV-6) methods via "Mudcat" dredges under water has the following advantages:

- (a) It lends itself to dredging operations in shallow areas, i.e., the floating Mudcat dredge has a maximum reach of about 15 feet below the water surface.
- (b) The configuration of the resultant bottom is more controllable with hydraulic dredging than it is with mechanical methods.
- (c) It is a continuous operation which will decrease the dredging operation time.

- (d) Water quality of the dredge pond is not significantly upset by the dredging operation.

The disadvantages are:

- (a) Clogging of the pump rock box by logs, large rocks, barbed wire, etc.
- (b) Dredging of sediment above water level requires first dragging that material back into the pond until adequate draft is available for passing the dredge.
- (c) The dredge is limited to movement along a straight line along a cable anchored at opposite shores.
- (d) Limited depth of sludge is 15 feet and more shallow.

The Mud Cat was successfully utilized for a demonstration project on a small lake in Prince George's County, Maryland. There are presently over 150 Mud Cat dredges in operation in the United States with many being used for restoration of lakes and ponds. A few of the recreational lakes and ponds on which the dredge has been successfully used includes: a number of lakes in the Township of Medford, New Jersey; parks and lakes for the Department of Natural Resources in West Virginia; Christmas Lake, Indiana; Valley Hi Lake in Colorado; Silver Creek Reservoir in New York; and Fort Snelling Beach, Minnesota.

3. PNEUMATIC DREDGES

Dredging technology in some foreign countries surpasses that of the United States. This is the case in Japan, where serious problems with in-place toxic substances prompted the development of dredges which are designed to remove contaminants rather than simply excavate river channels. A significant advancement in dredging technology for removing contam-

inants was the improvement of a pneumatic dredge.

All commercially available pneumatic dredges share the same basic operating principle, namely that of an airlift. The dredges differ with regard to size, dredging capacity, mobility (on land or mounted on barge) and other characteristics.

Most of these pneumatic dredges are fully or in part assembled on site for a specific use. Figure IV-7 exhibits the schematic of a simple airlift dredge as it can be employed for dredging of rivers. The dredge can be stationed and operated on land.

It is a dredging system that consists of a partially submerged vertical-recovery pipe into which compressed air is injected at a calculated depth below the water surface. The units are more efficient in deep water than in shallow water. The process of the buoyant air rising to the surface within the recovery pipe causes the air/water mixture to overflow from the surface end of the pipe due to the density reduction in the upper pipe section and the hydraulic head of water outside the pipe.

As the water flows into the submerged end of the recovery pipe which is positioned as close to the bottom as practical, the in-rush of water picks up and transports the bottom sediments through the pipe to the surface where the solid/water mixture is discharged into a recovery barge. The flow can be characterized as two phase (water and solid) below the air-injection point and three phase (water, air, and solids) above the air-injection point. The principle is close to vacuuming the bottom, and most of the sediments raised from the bottom are drawn directly into the intake of the recovery pipe, markedly controlling turbidity.

A slightly more sophisticated type of pneumatic dredge employs a

pumping system which consists of three large steel cylinders, usually of the same diameter and height. A short suction line is located at the bottom of each cylinder and at the top of the cylinders, and an air supply and release line extends to the surface and down into the lower reaches of each cylinder. The short suction pipe, which penetrates through into each cylinder, is equipped with a rubber-seated one way flow check valve. Once a cylinder fills from the static waterhead, compressed air is pumped into the cylinder to raise the water content within the cylinder to the surface. The flow causes bottom sediments to enter the cylinder and be raised to the surface by an injection of compressed air. With the combination of three cylinders operating in different time cycles, a continuous flow is maintained as the air is supplied to each cylinder by an air supply regulator or distributor.

Another commercially available dredge that has the same basic operating principle is a modified version of the one described above. The modifications include a new one way flow check valve design to prevent solids being caught and stuck in the valve. Strainers have also been provided at the inlet and suction pipe to reject large objects, while an electrical reverse-discharge detector is contained in the suction pipe to prevent such discharge.

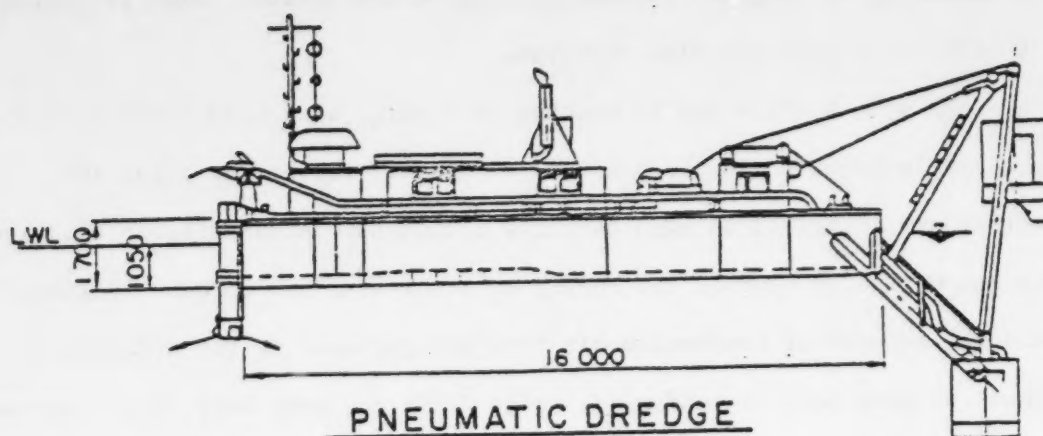
The Pneuma Dredge is a dredging and transport system which has been developed by Pneuma International S.A., an Italian firm. The dredge design uses compressed air for pumping and uses hydrostatic pressure to remove materials from the bottom. The system has been used in most larger standard dredging applications and has achieved acceptance, particularly in situations involving the removal of sediments from channels and harbor areas. It is claimed that very little sedimentation

is caused by cutting and removal actions of the system. High percentages (60-80%) of solids are also reported.

The system, which can be mounted on a barge, also uses three cylinders grouped together to form a pump body. Special valves for inlet and outlet are installed on each of three cylinders. A distributor functions to automatically control the supply of compressed air to each cylinder and the exhaust of compressed air from the cylinder to the atmosphere. When the pump body is submerged, water fills the pump body after lifting the inlet valve in each cylinder due to the hydrostatic head. The water, or the material to be dredged, enters the pump body through an inlet tube which extends below the pump body and to which may be attached various suitable shaped shovels. When the pump body has been filled, the distributor supplies compressed air to the pump body. The inlet valve closes because the pressure inside the pump body is now greater than the ambient hydrostatic pressure, and the air pressure acts as a piston, forcing the material inside the pump body out through a pipe which extends to the lower portion of the pump body. When the cylinder has been almost emptied, the distributor vents the air in the cylinder to the atmosphere and equalizes the cylinder internal pressure with atmospheric. This naturally creates a pressure differential between the inside of the cylinder and the hydrostatic pressure.

Figure IV-8 presents specifications and a schematic of such a larger pneumatic dredge mounted on a barge. It is a Japanese system and differs slightly from the specifications as given in Table IV-6 for the even bigger Italian Pneuma Dredge.

Different pump suction heads have been used. Figure IV-9 displays the two most common Japanese suction heads, a Pot Type, and a Swing



Dredging Capacity: Dredging Depth 5 m below water surface
 Rated Capacity 60 m³/hr
 Working Distance 30 - 150 m

Sludge Sampling Equipment:

Capacity 0.5 m³ x 2 units
 Diameter of delivery pipe; 105 mm
 Type of Valve: bevel valve/ball valve

Generator:

230 PS @ 1,800 rpm
 180 KVA

Vacuum pump:

Capacity: 7 m³/min x 7 kg/cm²
 Motor: 15 KW x 440 V

Compressor:

Capacity: 72 m³/min x 7 kg/cm²
 Motor: 55 KW

Winch:

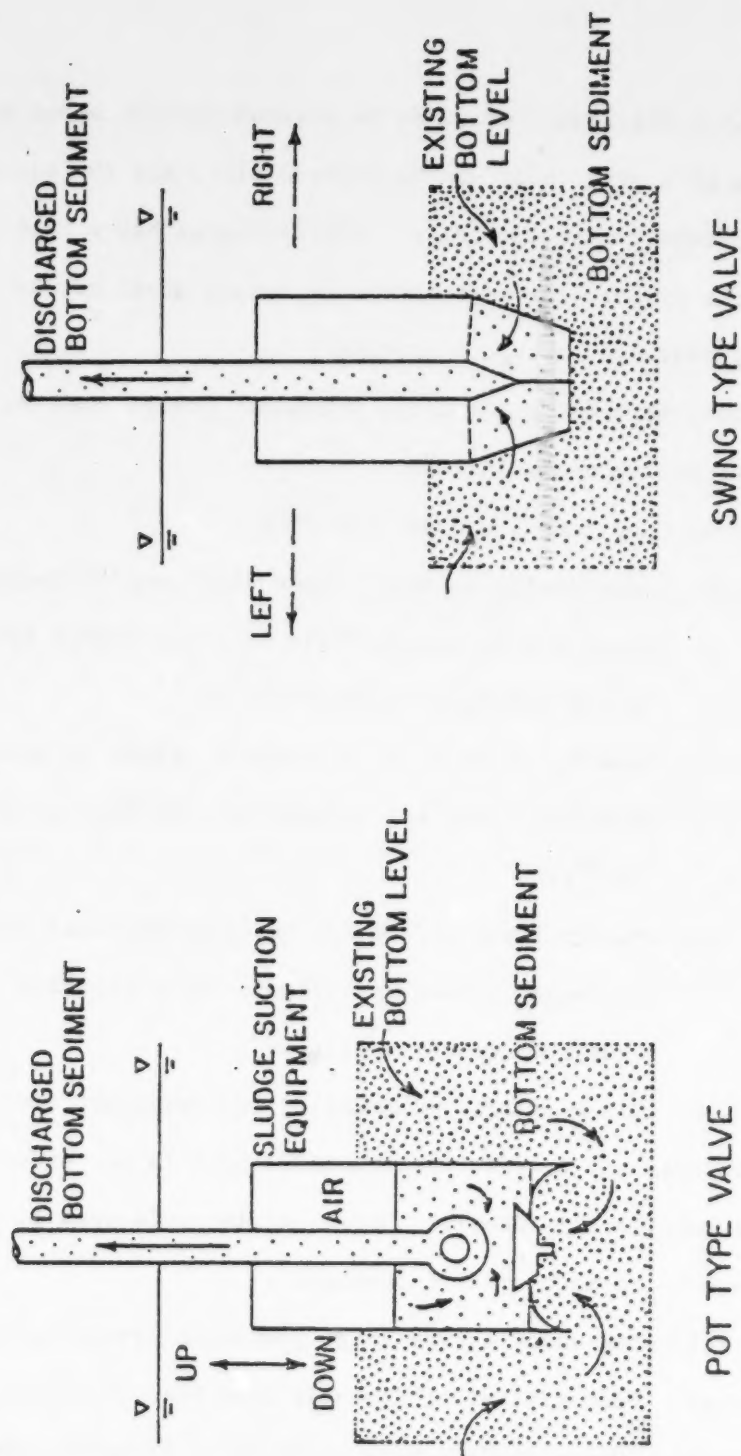
Three Drum Type x 2 units

Intake & Delivery Pump: 0.36 m³/min., 0.22 m³/min

SOURCE: E.P.A. - 600/3-78-084
 "Management of Bottom Sediments
 Containing Toxic Substances."

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 FIGURE IV-8

OUTLINES AND SPECIFICATIONS OF A
 TYPICAL PNEUMATIC DREDGE (JAPAN)



SOURCE: E.P.A.-600/3-79-102
 "Management of Bottom Sediments
 Containing Toxic Substances."

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FIGURE IV-9

TYPICAL POT TYPE AND SWING TYPE
 PNEUMATIC PUMP SUCTION HEADS

Type. Both tools lend themselves to environmentally sound dredging. The bottom of a water body can be dredged flat, and the suction heads do not generate excess turbidity. The discharge has a high mud content and with the proper size equipment, the dredge spoil can be discharged for a long distance through a pipeline.

Specific advantages for using pneumatic dredge systems, especially for contaminant removal, include:

- (a) Continuous and uniform flow.
- (b) Practically no wear, since there are no mechanisms in contact with the abrasive mixture, except for the self-acting spherical rubber valves.
- (c) Removes up to 60 to 80 percent solids by volume, thus reducing costs and hazards in contaminated dredge spoil disposal.
- (d) Particularly suited for dredging polluted material, since it causes little disturbance while dredging and, therefore, limits secondary pollution.
- (e) Can be readily dismantled for transport over highways.

A disadvantage is that the pneumatic pump is not effective in areas involving considerable debris. Large debris would tend to clog the inlet since there is no mechanical cutterhead.

The following examples are large-commercially-available pneumatic-type dredges: Pneuma (Italy), Pressair Sand Pump (Germany), and the Oozer (Japan). Oozer dredges were employed at Yokkaichi Port Japan, and the Shibaura Canal, Japan. The use of such a dredge in the United States is planned for dredging the Kepone-contaminated sediments of the James River, Virginia, and has been used in Duwamish Waterway in Seattle, Washington.

C. TRANSPORTATION OF DREDGED SEDIMENTS

Several options are available for conveyance of dredge spoil. The selection of an appropriate transportation system for a specific project will depend upon various factors, including dredging method, site restrictions, distance of transportation, mode of operation (continuous/intermittent), and infrastructure, geography, etc.

Four types of transportation system can be distinguished, i.e., barges, dump trucks, pipeline, conveyors. Combinations may also be considered, of course. Any dredge spoil with high water content should be handled such that spills do not occur. Control measures are necessary to prevent secondary pollution.

A detailed description and evaluation of different types and systems of transportation of dredge spoil is not presented. Ample information on this subject is available elsewhere.

D. DEWATERING OF DREDGED MATERIAL

The type of mechanical or hydraulic dehydration equipment to be selected depends in part upon the applied dredging methods. The location where the dehydration equipment is to be installed must be chosen in each case with consideration of, and in conformity to, the actual conditions of dredging.

Solid-liquid separation is an indispensable unit-process in a dredging operation if contaminated dredge spoil is to be handled. Release of polluted interstitial water into the environment could cause severe secondary pollution.

Several different dehydration techniques are readily applicable. They include:

1. SEPARATION BASINS

Separation basins are generally earthen settling ponds, often consisting of a series of ponds with the first preceded by screening equipment. The deposited sand and gravel is removed either following the completion of the dredging operation or concurrently during the dredging operation by means of a secondary dredge employed within the settling pond.

The settling of fine suspended solids can be enhanced by the addition of chemical coagulants. Operating and chemical costs for such systems must be carefully evaluated. An obvious disadvantage of settling basins is the land requirements.

2. ELEVATED BINS

Elevated bins as would be expected are a form of settling basins into which the dredged slurry is pumped directly and often used two to a series. Bins can be used for removal of particles down to 75 to 100 microns (200 mesh).

Advantages of elevated bins are that the settled solids can be loaded directly onto trucks. The bins have self-cleaning steep sloped sides, and they are not subject to clogging problems unlike other hydraulic separation systems.

Disadvantages are that generally after two to three hours of operation, the bins must be decanted and drained. When a continuous draining system is used, the operation becomes very messy due to spillage and the precise control required for the dump gates.

3. FILTRATION

Filtration systems using uni-flow filters, cartridge filters, large diameter fabric filters and sand filters are based on a combination of

straining and sedimentation principles. The straining effect is that particles larger than the filter pores will not pass through the filter media; sedimentation occurs when the fluid drag on the particle is less than the amount required to keep the particle suspended.

In general, the use of mechanical filters is limited to slurries with low suspended solids concentrations and to situations where a high quality effluent is required, such as when the filtrate is being discharged back into the dredged body of water.

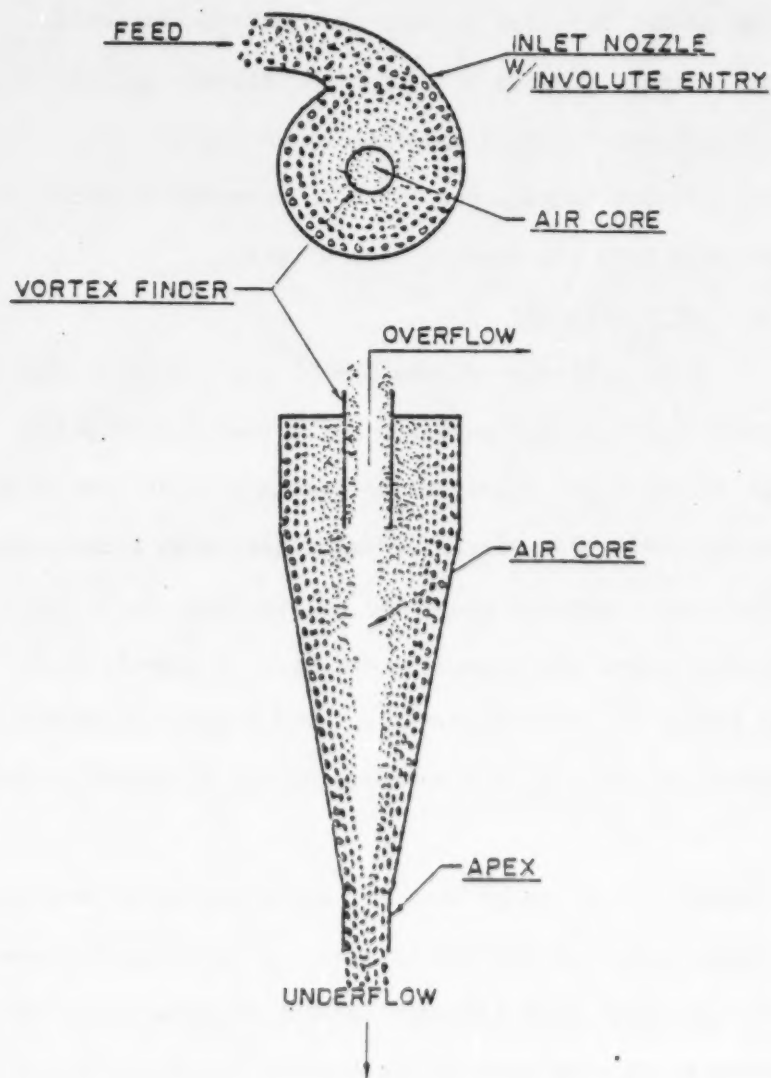
4. HYDROCYCLONES

Hydrocyclones (Figure IV-10) are conically shaped devices typically installed in a vertical position. The feed stream enters the cone through a tangential inlet which imparts a rotary vortex movement within the cone. The vortex movement generates a centrifugal force in the fluid and separates suspended solids from the fluid. The heavier solids move along the cone wall and drop by gravity to an outlet opening at the bottom of the hydrocyclone. The lighter fluid moves inward to the center of the cone and escapes through an overflow outlet at the top.

Hydrocyclones can be used to remove particles down through the fine sand range, i.e., 74 microns in size. A study by Oklahoma State University indicated that although hydrocyclones are not applicable to dredge material with high solids content and the high viscosity typical of the material tested, (that) hydrocyclones could be applicable to sandy dredged material with low organic content.

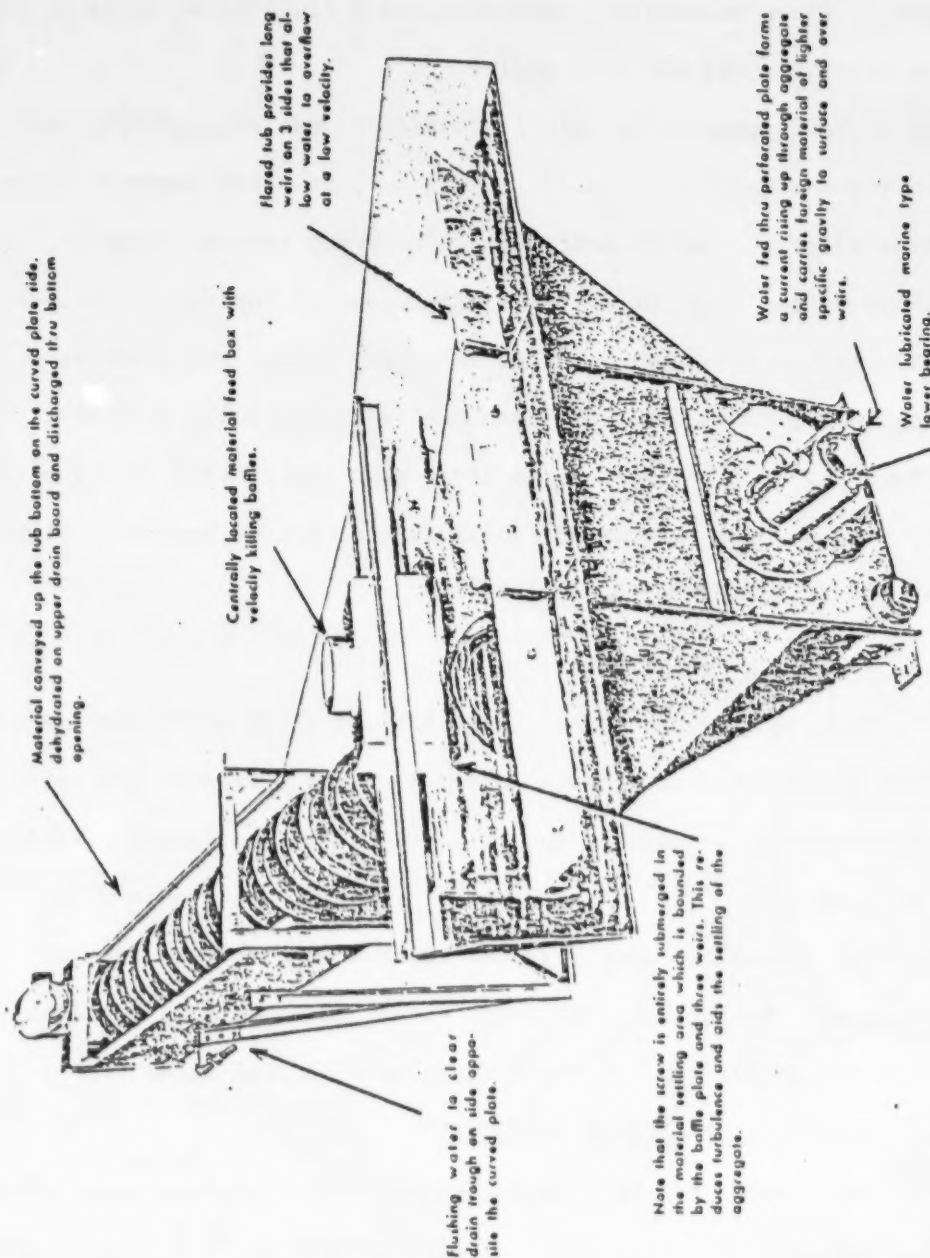
5. SPIRAL OR SCREW CLASSIFIERS

Classifiers (Figure IV-11) used in conjunction with small wetwell or hydraulic "scalping" tanks are used to elevate the blended and settled



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FIGURE IV-10

HYDROCYCLONE SCHEMATIC



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FIGURE IV-11

WASHER-CLASSIFIER

materials, removed in preliminary processes, to a point of discharge. The action of the large diameter screw agitates the sand and thus removes the adhering finer materials. Counter-flowing flush water helps to wash the fine particles off the sand grains.

The material removed by spiral classifiers has a relatively low moisture content and can be readily handled on standard conveyor belts.

Compared to the use of settling basins which require secondary dredge removal systems, the principal advantage of "hydraulic" solids separation is the elimination of the secondary dredge and associated operating costs. The number and combination of hydraulic scalpers, classifiers and hydrocyclones for a particular application is a function of flow rate, material processed, and amount of solids handled. Pilot plant studies should precede final design.

E. ELUTRIATE TREATMENT

Elutriate (Supernatant) treatment and spoil stabilization should be applied if contaminant levels exceed standard levels of concentration which can safely be handled by the selected method of disposal, reclamation or reuse.

The full technology developed for wastewater treatment can be capitalized on. Biological, chemical, and physical methods are available to remove metals (particularly heavy metals) from water.

1. BIOLOGICAL ELUTRIATE TREATMENT

Heavy metal removal can be accomplished with completely mixed anaerobic filters. The metals are precipitated as sulfides, carbonates, and hydroxides and are removed from the filter as a slurry that accumulates in the bottom solids collection device.

A different widely used method is heavy metal uptake by acclimated

activated sludge. It is possible to maintain a thriving culture of activated biota even in the presence of high levels of mercury, cadmium, or zinc. These metals are rapidly removed through metabolic processes and biological flocculation.

2. PHYSICAL/CHEMICAL ELUTRIATE TREATMENT

A variety of methods are available for chemical or physical removal of (heavy) metals from dredge spoil elutriate.

The surface acidity of activated carbon, for instance, adsorbs metals by forming various hydroxogroups.

Or, the hydroxides of various metals precipitate sequentially by gradual increase of pH. Substances for neutralization include lime, crusted limestone, caustic soda, ash, or anhydrous ammonia.

Reverse Osmosis and Ion Exchange is especially attractive where water quality requirements dictate high quality effluent. Subsequent recovery of the contained metals is a possibility.

Ozone is a powerful oxidant and is known to react with many organic compounds. Hence, an attack by ozone on a soluble metal-organic complex frees the metal so that it can precipitate from solution. This last method is of interest, since it is the organics in sediments which absorbs large amounts of (heavy) metals.

F. DREDGE SPOIL FIXATION

The traditional idea that hazardous wastes can be simply dumped or diluted has given way to the realization that all wastes ultimately are returned to the environment. There is a finite limit on the ability of the environment to absorb waste materials and remain unaltered.

Waste fixation is an increasingly applied method of dealing with the secure disposal of large quantities of toxic materials. Waste

fixation, or dredge spoil fixation in the case of contaminated sediments, is for the most part synonymous with stabilization/solidification. Chemical fixation and stabilization/solidification are general terms used to designate processes that can be used to immobilize, isolate, or contain waste materials.

The ideal fixative renders the (toxic) contaminants chemically nonreactive and immobile so that no secondary containment is necessary. For example, incorporation into a stable crystal lattice would effectively isolate the contaminants from any environmental interactions. Maintaining the pH in the range of 9 to 11 immobilizes the majority of multivalent cations as insoluble hydroxides.

Dredge spoil with high concentrations of particular cations could be treated with fixatives chosen specifically to immobilize these contaminants. Anions, although typically much less toxic, are much more difficult to bind into an unleachable product (same problem encountered in chemical in-situ stabilization). Hence, chlorides and sulfates, the most common anionic waste components (copper components, for example), have to be dealt with differently (physical isolation).

The ideal fixing process does not require extensive heat treatment nor large amounts of energy-intensive reactants. Also, the material should be reclaimable by some reasonable technique as some of the contaminants (metals) are predicted to be in a critical supply in the future.

There exist a large number of fixation methods which are now available or are under development, all having as their goal the safe, ultimate disposal of hazardous wastes. Ultimate disposal implies the final disposition of persistent, nondegradable cumulative and/or harmful wastes.

Three primary goals of fixation of hazardous waste for ultimate disposal generally are: (a) to improve the handling and physical characteristics of the waste, (b) to decrease the surface area across which transfer and loss of contained pollutants can occur, and (c) to limit the solubility of any pollutants contained in the waste. These goals can be met in a variety of ways, but not all techniques attempt to meet all three goals. Thus, individual fixation techniques may solve one particular set of problems, but be completely unsatisfactory for others.

The important attributes, advantages and disadvantages of the following major categories of industrial waste fixation systems are discussed:

- (1) Lime-based techniques.
- (2) Cement-based techniques.
- (3) Thermoplastic techniques (including bitumen, paraffin and polyethylene).
- (4) Organic base fixation techniques.
- (5) Silicate base fixation techniques.
- (6) Sulfur base fixation techniques.

Since these waste fixation systems vary widely in their applicability, cost and pretreatment requirements, many are limited as to the types of waste that can be economically processed. Selection of any particular technique for dredge spoil fixation should include careful consideration of the containment required, the cost of processing, the increase in bulk of material, and the changes in handling characteristics.

The design and location of any landfill or engineered encapsulation that will eventually receive the fixed mass is also a major consideration in deciding on the degree of containment and the physical properties

which will be required.

Each fixation agent should be thoroughly tested before application. Two types of standardized tests are recommended: (1) a short-term elutriate test, and (2) a longer-term leach test.

1. LIME BASE TECHNIQUES

Waste fixation techniques based on lime products usually depend upon the chemical reaction of lime and its variations with a fine-grained siliceous (pozzolonic) material and water to produce a concrete-like material. A detailed discussion was previously presented on the different types of lime and their in-situ application. Much of that discussion also pertains to lime-based dredge spoil fixation.

There are several advantages of lime-based techniques which produce pozzolonic cements: the materials are often very low in costs and widely available; little specialized equipment is required for processing as lime is a common additive to neutralize wastes; the chemistry of lime-pozzolonic reactions is relatively well-known; and extensive dewatering is not necessary because water is required in the setting reaction.

A disadvantage of lime-based systems is that lime and other additives (slag, gypsum, etc.) add to the weight and bulk to be transported and/or landfilled. Also, uncoated lime-fixed materials may require specially designed landfills to guarantee that the material does not lose potential pollutants by leaching.

2. CEMENT BASE TECHNIQUES

Most hazardous wastes, slurried in water, can be mixed directly with common cement or portland cement. The particulate matter will be solidified by the rigid matrix of the hardened concrete.

This procedure is especially effective for dredge spoil (wastes) with high levels of toxic metals, since at the pH of the cement mixture most multivalent cations are converted to insoluble hydroxides or carbonates. Metal ions may also be taken into the crystal structure of the cement minerals that form.

Some materials in the waste may actually increase strength and stability of the waste concrete (sulfides, asbestos, latex, etc.). However, the presence of certain inorganic compounds in the dredge spoil and/or the mixing waters can be deleterious to the setting and curing of the mix. Organic materials (silt, clay, lignite, decaying biomass) may affect adversely the integrity and strength of the hardened product.

Metal salts (manganese, tin, zinc, copper, lead) may cause significant reductions in physical strength. Mixtures of sodium silicate and cement have shown to allow a more rapid set with no retardation from metallic ions.

Advantages of cement-based fixation techniques include: raw materials are plentiful and inexpensive; the technology and management of cement mixing is well known; the equipment is commonplace and specialized labor is not required; extensive dewatering of the dredge spoil is not required; the natural alkalinity of the cement used can neutralize acids; leaching characteristics can be improved where necessary by coating the resulting product with sealant (asphalt, vinyl) or by polymer-impregnation; the amount of cement used can produce very high bearing capacities making the waste concrete good subgrade and sub-foundation material.

Disadvantages of cement based techniques include: relatively large amounts of cement are required. This effects weight and volume of the final product; uncoated cement-based products may require a well-designed

landfill or burial; leaching by mildly acidic solutions may pose a problem; and cement is an energy intensive material.

3. THERMOPLASTIC TECHNIQUES

In processing dredge spoil with bitumen, or other thermoplastic material, the waste is dried, heated, and dispersed through a heated plastic matrix. The mixture is then cooled to solidify the mass. Variations of this fixation system can use other thermoplastic materials such as paraffin or polyethylene.

The process requires some specialized (may be asphalt-mixing) equipment to heat and mix the waste and plastic matrix. The ratio of matrix to dredge spoil is generally quite high, 1:1 to 1:2 fixative to waste, dry weight. The matrix and the dry waste must be mixed at temperatures ranging from 130°C to 230°C.

A more economical variant of the above process uses an emulsified bitumen product which is miscible with wet sludge (important for in-situ stabilization). With this process the mixing can be done at any convenient temperature below the boiling point of the mixture. The overall mass must still be heated and dried before it is suitable for disposal. Ratios of emulsion to waste of 1:1 to 1:2 are necessary for adequate incorporation.

Major advantages of thermoplastic-based disposal systems are: the leach loss rates are significantly lower than those observed with cement-based systems; by disposing of the stabilized mass in a dry condition, the overall volume of the waste is greatly reduced; most fixatives are very resistant to attack by aqueous solutions; microbial degradation is expected to be minimal; and most matrices adhere well to incorporated materials.

The principle disadvantages of thermoplastic-based disposal systems are: expensive, complicated equipment requiring highly specialized labor may be necessary for processing; there is a risk of fire in working with organic materials such as bitumen at elevated temperatures; during heating, some mixes can release objectionable oils and odors causing secondary pollution; large amounts of energy may be required to dry the dredge spoil; incorporating wet wastes greatly increases losses through leaching; strong oxidizers may cause oxidizing reactions and deterioration of the mix; dehydrated salts incorporated will slowly rehydrate if the mixture is exposed to water causing the solidified material to fragment.

4. ORGANIC BASE TECHNIQUES

Some organic base solidification techniques have been developed which make use of polymeric and resinous materials.

Por Rok and Por Rok Epoxy Sealant are both grout material manufactured by Hallemete Division, Sterling Drug Company. Por Rok is a gypsum based material and, consequently, will not retain structural integrity when immersed in water.

Por Rok Epoxy Sealant is a synthetic epoxy material which is mixed with a coarse aggregate material and is used as a grout or surface sealant. This agent was very successful when used for stabilization of pesticides.

The most thoroughly tested polymer-based fixation technique is the urea-formaldehyde (UF) system. The polymer is generally formed in a batch process where the wet or dry dredge spoil is blended with a prepolymer in some type of a mixer; then a catalyst is added and mixing is continued until the catalyst is thoroughly dispersed. The polymerized waste forms a spongy mass that traps the solid particles (and contaminants).

The advantages of UF resin system are: less fixative is required for solidifying the dredge spoil than with cement; the finished solidified polymer must be dried before ultimate disposal; low density (light fixative) reduces transportation cost and disposal (volume) requirements; the solidified resin is nonflammable and high temperatures are not required for forming the resin.

Other organic polymers (polyester resin developed by Washington State University) are very effective for metal ion waste, kepone and PCB.

The major disadvantages of organic resin techniques are: no major reactions occur in the solidification system that chemically bind the potential pollutants; the particles of waste material are merely trapped in an organic resin matrix; catalysts used in the UF system are strongly acidic and require a pH 1.5 ± 0.5 for solidification to occur in a rapid manner (the low pH can cause release of many contaminants, however this effect can be beneficial, if controlled, to extract easily soluble contaminants); some catalysts are highly corrosive and require special mixing equipment; the reactions producing the final resin may release fumes that can be harmful even in low concentrations; some cured resins are biodegradable; specially designed landfills may be required.

5. SILICATE BASE TECHNIQUES

Ontario Liquid Waste Disposal, Ltd., developed a procedure for fixation of spoil. Their process involved the addition of an acid agent followed by an amending agent with dosing controlled through observation of pH levels. The solidification process is based upon the production of stable silicate compounds analogous to natural geologic materials.

All inorganic wastes from heavy, medium, and light industries such as plating wastes, etc, containing acids, chromium, copper, iron, magnesium, mananese, nickel, zinc, cadmium, lead, mercury, vanadium, chlorides, sulfates, phosphorus and virtually any inorganic chemical or combination thereof can be stabilized.

The process is ineffective against some organic wastes, but organic contents of up to 20% of the volume of the formulated inorganic wastes have been treated successfully on a case to case basis. The formula is proprietary.

Stablex Corporation patented a technology described as Sealosafe which involves adding two silicate-based powders to the waste (watery dredge spoil). The slurry mixture gradually sets into a rigid, rocklike cast. Due to its physical and chemical form this mass is referred to as synthetic rock.

The physical and chemical interactions which take place simultaneously are referred to as the mechanisms of crystal capture. Several additives can be used to enable the crystal capture mechanism to operate under optimum conditions, depending on waste type.

All inorganic and some organic wastes can be treated. The process is exceptionally successful in treating all heavy metals, arsenic, mercury and asbestos. The process also deals with anionic wastes, such as (metal-) floride, chloride, etc.

Oil, solvents and greases (hydrocarbons) which are not miscible with an aqueous phase, cannot be solidified. The water content cannot exceed certain ratios.

The Japanese company, "Takenaka" is also a producer of fixidation agents. Many of their mixtures are a variation of a basic silicate-

based fixation agent. The exact chemical formulations are proprietary. The Takenaka technology has had widespread operational use in Japan under a range of conditions.

Chemfic, Inc., is another organization that develops and markets silicate-based fixation processes. Soluble silicates and cements are mixed with the wastes to produce a gelling reaction that is followed by hardening.

A mobile treatment plant that can handle up to 380,000 liters/10hour shift is provided. The additives consist of up to 10% (volume) of the waste (dredge spoil).

Most types of wastes can be accepted for this processing. The additives react with polyvalent metal ions producing stable, insoluble, inorganic compounds. The process is usually custom designed for each type of waste material.

Certain organic compounds may require pretreatment to allow the Chemfix stabilization/solidification system to be used.

6. SULFUR BASE TECHNIQUES

Sulfaset is a proprietary agent distributed by Rondustrial Corp. It includes both sulfur and cement in the foundation. Details about the mechanisms of the corresponding fixation technique were not available.

Another mixture is based on molten elemental sulfur. This fixative is rapidly mixed with dredge spoil. Environmental consequences of application of molten sulfur are as yet unknown, however.

G. DISPOSAL/REUSE

The available methods of environmentally sound disposal, reclamation, or reuse of dredge spoil are intimately related to the effluent quality of the treated liquid phase and the chemical, physical and bio-

logical characteristics of the stabilized/solidified solid phase.

1. ELUTRIATE DISPOSAL

If the treated liquid satisfied certain required standards (see Chapter IV), it can be discharged into natural water bodies in a safe manner. Should it prove more economical to treat the supernatants only partly or not at all, the elutriate can be discharged into a nearby sewer system if the downstream treatment plant is capable of handling this extra load of wastewater (metals). It is obvious that it would be least complicated if the liquid phase after separation from the dredge spoil could be discharged into a sewer without expensive treatment either in-place or some distance away from the dredging site.

In general, there are six ways of direct and indirect reuse of supernatant:

- (a) Municipal reuse
- (b) Industrial reuse
- (c) Agricultural reuse
- (d) Recreational reuse
- (e) Groundwater recharge
- (f) Surface water recharge (river, lake, pond, ocean, etc.)

Receiving-water standards differ accordingly.

2. SOLIDS DISPOSAL

The available alternatives of disposal must be evaluated on the basis of costs, regulatory requirements, and general technical and environmental feasibility.

When considering any waste for disposal, the potential for resource recovery or reuse of hazardous constituents and/or other materials

within the particular waste (dredge spoil) should be examined first. Where recovery or reuse is not technically possible or economically practical and where land disposal does not appear environmentally acceptable, then other alternatives might be considered, such as incineration, deep well injection, detonation, ocean disposal and engineered encapsulation.

In the following four different methods of disposal/reuse of (stabilized) dredge spoil are discussed:

(a) Reuse as Construction Material

The most secure final form of treated dredge spoil is a monolithic mass which has good dimensional stability, freeze-thaw resistance, low permeability, a high bearing capacity, and resistance to attack by chemical and biological agents. An end product such as this could be used as a foundation for buildings or roads.

Crucial for this kind of reuse, as for any other, is some knowledge about the behavior of the potentially toxic constituents in the new environment. Acidic soils or solutions could cause the disintegration of the stabilized and solidified material. The presence of groundwater may be detrimental for both the groundwater (contamination) and the stabilized and reused dredge spoil (dissolution).

In some cases it may prove beneficial to install an impermeable liner beneath the subgrade of a road or the foundation of a structure which is to be made of reused dredge spoil.

(b) Reuse as Fertilizer

To be completely effective, the dredge spoil fixation should produce a final mixture which has physical and chemical (and biological)

properties such that its disposal doesnot permanently render the land unsuitable for alternative use.

Enriched with nutrients the treated dredge spoil may be suitable for agricultural purposes. Thorough testing is recommended both with regard to the most effective fixation technique and the environmentally safest application.

In cases where the major contaminants are multivalent cations and/or high levels of salts, it seems highly unlikely that it would be possible to produce treated dredge spoil, which might be suitable for agricultural use.

The action of organic acids normally produced by the biological activity in agricultural soils would be expected eventually to mobilize even the most tightly bound contaminants. Such mobilized constituents would then be taken into the food chain or washed into the groundwater. Although trace elements are essential to plant growth in minute quantities, they become toxic in higher concentrations.

(c) Ocean Dumping

Recent ocean dumping legislation was enacted to control the use of the ocean as a waste disposal sink. At present, persons wishing to discharge to the ocean must obtain permits from EPA, or the Army Corps of Engineers in the case of dredge spoils.

It is EPA's intention that ocean dumping be strictly regulated where discharge might adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities.

Technically, economically and operationally ocean dumping lends itself particularly for disposal of dredge spoil which was generated

near the ocean (harbor, estuary, close river). Treatment of the dislodged material in some cases may not be necessary and transportation can be accomplished by barges.

The Army Corps of Engineers has years of experience in dredging (river, estuary, harbor) and ocean disposal of unpolluted material. Hence, for more information on technical aspects of ocean dumping one is referred to the U.S. Army COE.

In order to obtain a dumping permit from the EPA for contaminated materials it is required to prove conclusively that the introduction of these materials into a certain marine environment will have no environmentally adverse side effects.

(d) Secure Landfill/Encapsulation

If any kind of reuse has to be ruled out because of possible resolubilization of the contaminants, and if ocean disposal is unfeasible, selection for safe land disposal is one of the most critical steps to undertake. Hydrologic, geologic and soil investigations must be conducted to develop a satisfactory containment (encapsulation) facility.

Secure landfilling or engineered encapsulation of contaminated dredged materials involves placing the (stabilized) dredge spoil in a land burial facility in such a manner that it is permanently removed from any sensitive environment. In general terms, such operations provide complete long-term protection for the quality of surface and subsurface waters from hazardous wastes deposited therein, and against hazardous to public health and the ecological environment.

Within recent years, governments have issued detailed regulations regarding the design and operation of chemical landfills which are generally applicable to encapsulation of contaminated dredged sediments. These criteria relate to three aspects of the design of such a facility,

i.e., site selection, lining and leachate prevention, and long-term operation and maintenance. Figure IV-12 shows the cross section of a schematized secure chemical landfill.

Potential sites for landfilling contaminated dredged sediments can be identified based on the typical criteria shown in Table IV-7. Detailed field studies are required before final site selection can be made. Since the size and location of a suitable disposal site depend on the actual dredging program selected, the detailed field studies and final site selection must await selection of an actual dredging program.

Leachate prevention through lining is one of the crucial design aspects. Proper design of an engineered encapsulation site secures the contaminated material so that the potential for these losses are minimized. This includes placing an impermeable barrier beneath the contaminated materials and an impermeable cap above it to prevent excessive infiltration of precipitation from entering the contaminated spoils. The concept of limiting infiltration and percolation to the greatest possible extent is a necessary part of the design plans for any facility.

A leachate-collection system should also be installed beneath the spoils, and if necessary, a leachate-treatment facility designed for these sites to collect and treat leachate that may be produced. An extensive groundwater monitoring system should be installed prior to deposition of any wastes to detect any contamination that might leach from the site and enter the groundwater system.

Features of a typical engineered encapsulation site include (see Figure IV-12):

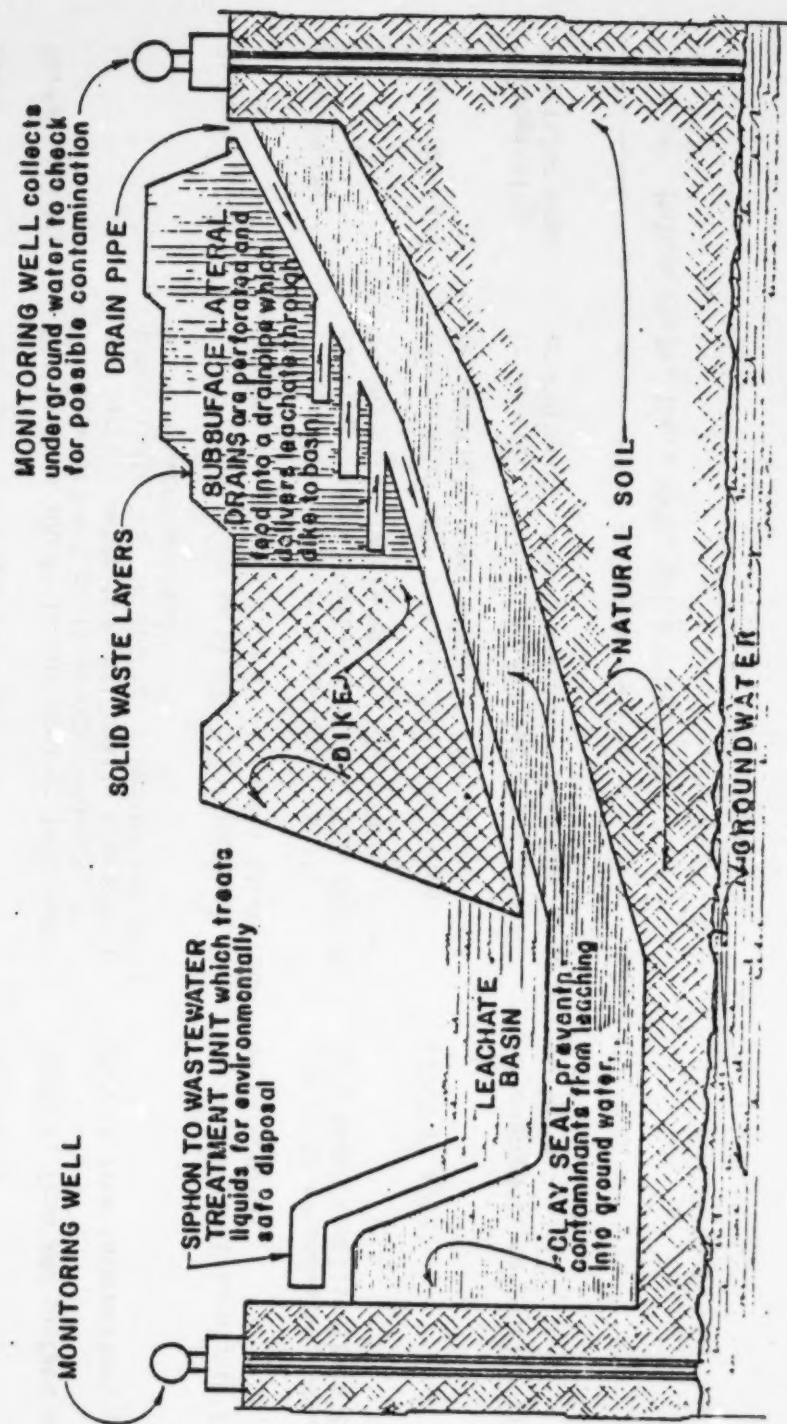
- A natural impermeable layer ($\leq 10^{-7}$ cm/sec) at least 4 ft. thick over the bottom of the site.
- Dikes (average height 14 ft.) lined with at least 2 ft. of

impermeable material ($\leq 10^{-7}$ cm/sec).

- A final impermeable cover ($\leq 10^{-7}$ cm/sec) at least 18 in. thick over the top of the site. This, together with the 5 percent slope given the top of the dredge material will facilitate runoff and minimize the amount of rainfall penetrating the fill.
- An 18-inch layer of select material for turf establishment over the top of the site. This will be seeded and graded and a vegetative cover established to stabilize the site.
- A system of monitoring wells into the site to monitor leachate generation (not shown).
- A system of drainpipes which delivers leachate through dike to leachate collection basin. From there a siphon uptakes the leachate and discharges it to the wastewater treatment unit.

An engineered encapsulation site is a humanmade structure and as such will require long-term maintenance and operation. Essential elements of a maintenance and operation program include:

- Continued compatible use of the land surface (e.g. ecological study, recreation, material storage, etc.).
- Structural maintenance sufficient to insure the integrity of the impermeable barrier.
- Proper collection and disposal of any leachate developed (either via on-site treatment or by removal to an adequate, off-site treatment facility).
- Monitoring to insure that contaminant losses to the environment are not occurring (i.e. air, biota, ground and surface water).



CROSS SECTION

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FIGURE IV-12

SECURE CHEMICAL LANDFILL

TABLE IV-7

TYPICAL CRITERIA USED TO SELECT AN ADEQUATE SITE FOR
AN ENGINEERED ENCAPSULATION FACILITY TO CONTAIN CONTAMINATED DREDGE SPOIL

Parameter	Unacceptable	Ideal
Soil	Permeability $>10^{-5}$ cm/sec. less than 3 ft. thick in-situ. ($<1.4 \times 10^{-4}$ cm/sec overlaid) Class I or II agricultural soils.	Permeability $<10^{-7}$ cm/sec, in-situ thickness $>10 \text{ ft.}$, soil passing #200 sieve $>30\%$, liquid limit >30 , plasticity index 15.
Slope	Deep gullies, slope over 15%	Slope $<10\%$
Surface Water	Closer than 300 ft to any pond or lake used for recreational or livestock purposes, or any surface water body officially classified under state law. In special flood hazard areas or recognized wetlands.	$>1000 \text{ ft}$ from any surface water body. $>200 \text{ ft}$ from intermittent streams.
Bedrock	Closer than 30 ft to highly fractured rock or carbonates, closer than 10 ft to all other rock.	More than 50 ft to highly fractured rock or carbonates.
Groundwater	Closer than 10 ft to groundwater, wells tapping shallow aquifers, closer than 1000 ft to any water supply well. Flow towards site.	$>50 \text{ ft}$ to groundwater, no wells or only deep bedrock wells within 2000 ft radius.
Committed Land	Closer than 1000 ft to parks, cemeteries, residential areas, historic sites, etc.	$>1500 \text{ ft}$ away.
Biologically Sensitive Areas	Endangered plant or animal habitats, unique or regionally significant environments.	No woodlands, no locally significant features.

Source: Malcom Pirie, Inc., 1978, White Plains, N.Y.

There is little experience with long-term operation of such facilities. Thus, there are uncertainties regarding operational costs. If no major problems occur, such costs should be minimal; however, if unforeseen problems occur, costs could be high.

H. PILOT PLANT STUDIES

It has been mentioned frequently in this Chapter that prior to selection of a final integrated program of dredging, treating and disposing of polluted deposits, pilot studies should be performed to design the best procedure in terms of environmental effectiveness, economic efficiency and geographic practicality. According to these criteria, decisions have to be made with regard to:

- (a) Hydraulic, pneumatic, mechanical dredging
- (b) Truck, barge, pipe, conveyer transportation
- (c) Dehydration processes
- (d) Mobile or stationary dehydration facility
- (e) Method and degree of treatment of supernatant
- (f) Method and degree of stabilization of solid phase
- (g) Disposal or reuse of treated supernatant
- (h) Disposal or reuse of stabilized solids
- (i) etc.

All of these decisions must reflect their mutual capability in order to devise an optimal system. Chemical, biological and mechanical tests must be conducted to evaluate the performances of alternate solutions.

B. Environmental Impacts of Control Alternatives

In considering any of the sediment control measures described in the preceding section to solve one environmental problem, it is important to consider the environmental impacts associated with each control measure.

Such impacts might include temporary deterioration of surface water quality due to sedimentation-induced turbidity, disruption of local flora and fauna; alterations in the composition of benthic and other aquatic life in a given area; noise, air pollution and transportation problems associated with construction activities and the potential introduction of chemical substances which could solve one problem but in the long run, create others. It is also important to recognize that these impacts must be evaluated on a site-by-site basis as management objectives for individual applications are likely to vary from site to site. For this reason, a general summary of the environmental impacts associated with each control alternative is presented in Table IV-8. Additional discussion of the impacts can be found in Chapter VIII of the report prepared by C.E. Maguire.

C. COSTS OF ALTERNATE SEDIMENT MANAGEMENT TECHNIQUES

1. GENERAL

Included herein are some examples of cost items that should be considered in evaluating the alternate control and removal techniques described in the preceding chapters.

The reader must be aware that there are many pitfalls in using "typical" cost data and curves such as are presented, especially when each alternate is greatly affected by site specific conditions.

Each table and curve for an alternate presented herein oftentimes cannot be used as an entity in itself. For example, it is likely that a site that needs an artificial liner will also require some form of slope protection as well as surface and groundwater control.

2. IN-SITU STABILIZATION

1. ARTIFICIAL LINERS

Table IV-9 presents a range of prices for material and

TABLE IV-8 SUMMARY OF ENVIRONMENTAL IMPACTS ON VARIOUS MANAGEMENT ALTERNATIVES

Alternatives	State of Development	Benefit	Short-Term	Detriment	Long-Term	(Potential) Detriment
A. IN-SITU STABILIZATION						
1. Physical	Non conventional approach	Immediate immobilization of contaminants; almost immediate rehabilitation and use of site possible; no archaeological, historic impact; localized action.	Same as 1.	Noise development on and beyond site; traffic impact due to construction;	Site Preservation	Contaminants remain in place.
	Many applications; mostly proven technology for synthetic membranes, admixed materials and natural soils; conventional slope protection;					Leachate development; gas and color generation; disintegration of stabilization system; medium-term elimination of berthing life; increased flood hazard possible;
2. Chemical	Mainly conceptual; some applications (Lime, cement, asphalt)	Same as 1.	Possible dust development; minor air, water pollution poss. possibly more expensive	Same as 1.		Same as 1.
	Purely conceptual;	No short-term disruption; none of the above impacts;	No immediate improvement;	Natural purification; no introduction of foreign substances; no danger of disintegration of stabilization system;		Degradation of chemical agent; dissolution; secondary pollution through chemical agent;
3. Biological						Extremely slow recovery of site; continuing environmental hazard; No near-future reclamation of site possible, long-term operation
B. DREDGING						
	Many applications of dredging of contaminated sediments in Japan; extensive experience in maintenance dredging in U.S.	Immediate and complete removal of contaminants; Immediate rehabilitation of site possible, labor and machine intensive operation (employment);	Major construction related impacts such as noise, air, water pollution; traffic; possibly very expensive	Complete removal of pollutants; No danger of remobilization of contaminants; Site restoration and rehabilitation possible; no maintenance problems at site; Improved of hydrodynamics; reduction of flood hazard		Site preservation not possible; slow ecologic recovery; historic aesthetic, archaeological impact possible secondary pollution possible;
a. Dredging Methods	pneumatic method not fully developed yet					

TABLE IV-8 CONTINUED

Alternates	State of Development	Short-Term			Long-Term	
		Benefit	Detriment	Benefit	Detriment	(Potential) Detriment
b. Transportation	fully developed techniques	-----	secondary pollution along transport routes possible;	-----	-----	-----
c. Dewatering	fully developed techniques	-----	Increased cost	removal of contaminated elutriate possible reuse of dredge spoil	-----	-----
d. Treatment	partly developed; some conceptual techniques; cont. research	no secondary pollution elutriatedisposal	Increased cost; increased dredge spoil volume;	more stable solids disposal possible; less potential for secondary pollution	Secondary pollution due to chemical agents	-----
e. Disposal/Reuse	Some conventional technologies available; continuing research;	-----	additional cost; disruption at disposal site;	resource recovery (reuse) contaminants can be closely controlled (landfill); no land requirement (ocean disposal);	Land requirements; environmental impacts at disposal or reuse site; long-term operation of landfill; secondary pollution possible;	-----
C. NO MANAGEMENT ACTION	few operation policies developed; but, most applied alternate due to lack of financial resources and data;	no expenses; no disruptions; no related impacts;	no immediate improvement	None expected	Contaminants remain in place; no control of environmental hazard; no recovery of site possible; waste of material and aesthetic resources; potential for unforeseen health and environmental impacts;	-----

installation of several types of artificial liners. As can be seen, the costs range from \$0.75 to \$8.32, installed.

Table IV-10 summarizes some of the costs involved in applying an artificial liner to a "typical" one acre site. The costs include the use of a layer of granular material, gravel layer for gas control and liner anchors, and a layer of topsoil and seeding. A 36 mil hypalon material was assumed to be the liner selected. A cost of \$1500 for clearing of trees and brush is included.

As noted in the Table, additional slope protection, site dewatering, site drainage and/or site fencing must also be considered.

With all of the above in mind, a cost of about \$155,000/acre can be assumed.

2. CONCRETE ENCASEMENT

Table IV-11 summarizes the average cost of using cement concrete or asphalt concrete to encapsulate a one-acre site. The data is based on a concrete mat, a layer of gravel bedding, and a layer of gravel fill for surface preparation. An allowance of \$1500 for clearing the site of trees and brush has also been included. Once again, additional slope protection, site dewatering, site drainage, and/or site fencing must also be considered. Access to the site will also be important.

In any case, an "average" cost of \$1,164,000/acre or \$450,000/acre is required for concrete and asphalt, respectively.

3. SLOPE PROTECTION

Table IV-12 presents costs associated with slope protection alternates constructed of: stone; timber sheeting; steel sheeting; and concrete. Since these costs are greatly influenced by the characteristics

of adjacent water bodies such as water depth and foundation, the costs are also shown based upon two depths, five-foot and ten-foot. The costs are presented per 1000 feet of channel length.

The stone blanket slope protection includes 2'-0" of stone and 1'-0" of compacted gravel and assumes that a 1:2 slope will be constructed. An allowance of \$35,000 per 1000 foot of slope was included for the costs of constructing the toe of the slope via a dragline system. It was also assumed that the existing slopes would have to be cut-back from a hypothetical existing vertical slope. Hence, an allowance for cut and fill was included. It was assumed that clearing was not required.

The cost associated with the slope protection options are based on only these costs to stabilize the embankment from further erosion. The costs to implement a slope protection system that involves complete elimination of leachate between the embankment and the river would most likely involve the costs for complete groundwater content.

The costs for the concrete retaining wall includes an allowance for temporary sheeting and excavation that may be needed to place the concrete. The base of the retaining wall was assumed to be 5' -0" long by 18 inches thick, resting on 12 inches of crushed stone. The wall was assumed to be two feet thick at its base.

4. CHEMICAL STABILIZATION WITH LIME

Table IV-13 summarizes several costs involved in stabilizing a one acre site to depths of one, five, and ten feet with lime at concentrations of 5,10, and 15%.

The characteristics of soil and contaminants will dictate the degree of stabilization required at each location. The amount of lime required should be determined in the laboratory.

TABLE IV-11
CONCRETE AND ASPHALT ENCASEMENT COST/ACRE

<u>ITEM</u>	<u>COST</u>	
	<u>CONCRETE</u>	<u>ASPHALT</u>
Concrete, Asphalt	\$ 726,000	\$ 261,360
Gravel and Fill	33,071	33,071
Site Clearing	+ 1,500	+ 1,500
Subtotal	\$ 760,571	\$ 294,431
Contingency @ 10%	<u>76,057</u>	<u>29,443</u>
Subtotal	\$ 836,628	\$ 323,874
Overhead, Administration, Profit @ 30%	<u>250,988</u>	<u>97,162</u>
Subtotal	\$ 1,087,616	\$ 421,036
Engineering, Boring, Survey @ 7%	+ 76,133	<u>29,472</u>
TOTAL	\$ 1,163,749	\$ 450,508/Acre

Note: Costs do not include slope protection, site dewatering, site drainage, or site fencing.

TABLE IV-12
SLOPE PROTECTION COSTS*

Item	Stone Blanket		Timber Sheeting		Steel Sheeting		Conc. Retaining Wall	
	5' Water Depth	10' Water Depth	5' Water Depth	10' Water Depth	5' Water Depth	10' Water Depth	5' Water Depth	10' Water Depth
Concrete	---	---	---	---	---	---	\$272,400	\$383,400
Conc. Anchor	---	---	\$62,500	\$62,500	\$62,500	\$62,500	---	---
Anchor Rods	---	---	12,500	12,500	12,500	12,500	---	---
Crushed Stone	\$22,230	\$34,440	---	---	---	---	---	---
Gravel	5,187	8,036	---	---	---	---	3,330	3,330
Temp. Sheeting	---	---	---	---	---	---	---	---
Dragline	---	---	---	---	---	---	25,000	30,000
Bucket	35,000	35,000	---	---	---	---	---	---
Misc. Excavation (not included above)	11,112	24,999	---	---	---	---	15,279	26,667
Timber Sheeting	---	---	50,000	100,000	---	---	---	---
Steel Sheeting	---	---	---	---	108,000	170,000	---	---
Subtotal	\$ 73,579	\$102,475	\$125,000	\$185,000	\$183,000	\$245,000	\$316,009	\$443,397
Contingency at 10%	+ 7,353	10,290	12,500	18,500	18,300	24,500	31,601	44,340
Subtotal	\$ 80,882	\$112,723	\$137,500	\$203,500	\$201,300	\$269,500	\$397,610	\$487,737
Overhead Admin. & Profit at 20%	24,965	33,817	41,250	61,050	60,390	80,850	104,283	146,321
Subtotal	\$105,147	\$146,540	\$178,750	\$264,550	\$261,690	\$350,350	451,893	634,058
Engr., Boring Survey at 7%	7,360	10,256	12,513	18,519	18,318	24,525	31,633	44,304
TOTAL	\$112,507	\$156,796	\$191,263	\$283,069	\$280,008	\$374,875	\$483,526	\$678,442

*Costs shown are costs per 1000 foot of channel, one side only.

TABLE IV-13
LIME STABILIZATION COSTS

<u>Soil Depth</u>	<u>LIME COST PER ACRE</u>		
	<u>Lime Concentrations (%)</u>		
	<u>5%</u>	<u>10%</u>	<u>15%</u>
1 foot	\$ 8,400	16,800	25,130
5 feet	41,930	83,860	125,790
10 feet	\$ 83,860	167,720	251,580

<u>Soil Depth</u>	<u>Labor Costs/Acre</u>		
	<u>5%</u>	<u>10%</u>	<u>15%</u>
1 foot	\$ 54	54	54
5 feet	\$ 66,719	66,719	66,719
10 feet	66,719	66,719	66,719

<u>Soil Depth</u>	<u>Fuel, Power and Equipment Rental/Acre</u>		
	<u>5%</u>	<u>10%</u>	<u>15%</u>
1 foot	\$ 34	34	34
5 feet	29,400	29,400	29,400
10 feet	29,400	29,400	29,400

<u>Soil Depth</u>	<u>TOTAL COSTS (INCLUDING O&P, ADMIN. ENGINEERING)²</u>		
	<u>5%</u>	<u>10%</u>	<u>15%</u>
1 foot	\$ 12,853	25,840	38,586
5 feet	211,229	275,386	339,543
10 feet	275,386	403,700	532,014

- Note:
1. One foot stabilization based on truck spreading. Five and ten foot stabilization based on line column stabilization.
 2. Total Cost figure consists of: Congingency @ 10%; Overhead, Administration Profit @ 30%; and Engineering, Boring, and Survey @ 7%.

It was assumed that one of several available commercial spreading vehicles would be used for mixing lime for those sites to be stabilized to one foot deep. A monthly rental cost of \$4,000/month, an effective spreading rate of 300 feet/minute, and a total of three workers were considered for the surface spreading process.

The cost for lime stabilization to depths of five and ten feet are based on the use of the equipment described in Chapter IV for lime column stabilization. A total of five (5) people are assumed to be required for the operation. A drilling rate of four holes per hour were allotted. A monthly equipment rental cost of \$5,000/month was assumed for the portable rig.

It should be noted that most likely one of the surface encapsulation methods discussed in Chapter IV will be needed in this conjunction with lime stabilization in order to prevent erosion due to wind, rain and ground water. Slope protection will also be required as well as surface water, drainage ditches. None of those costs are included in Table IV-13.

If an 8-inch thick concrete drainage ditch, 3 feet wide at the bottom, with three-foot wide slopes was constructed for surface water control, the additional costs would be on the order of an additional \$85,000 per 1000 foot of ditch.

3. DREDGING

1. DREDGING COSTS

The proper planning, design, and cost estimating of a dredging project requires that several factors be considered. Included among these are:

- a. The quantity of material to be dredged.
- b. The location, size and type of the dredge to be used.
- c. The characteristics of the material to be dredged.

- d. The percentage of sand and gravel present.
- e. The effluent water quality requirements.
- f. The available land area for containment facilities.
- g. The ultimate land use of the containment area, as well as the disposal area.
- h. The environmental sensitivity of the site.

Table IV-14 presents a summary of costs for a few recent dredging projects. The costs range from \$1.39 per cubic yard of dredged spoil to \$4.05 per cubic yard. It should be noted that these costs do not include any costs for treatment of the dredged material.

2. DEWATERING

Table IV-15 and IV-16 give the reader an idea of the additional costs that should be considered for a secondary step in handling dredged material. Three alternatives are shown:

Alternate No. 1 assumes that space is available so that the dredged material can be transferred to an earthen separation basin. Sand and gravel is then separated from the settled dredged spoil via bar screens and classifiers. It is assumed that the basins do not require any special construction, e.g., special liners. Costs for collecting and treating the separation basin overflows and/or the classifier overflows are not included.

Alternate No. 2 is based on a system that uses elevated bins and tanks followed by hydrocyclones for sand and gravel separation.

Alternate No. 3 is similar to Alternate No. 2 except that a hydraulic (gravity) thickener acts as the final separation step. It is possible to construct systems like Alternate No. 2 and 3 on flat bed trucks and, in effect, develop a portable separation system.

A Mud-Cat dredge described in an earlier chapter was assumed for

secondary dredging of the dewatering site. The dredge is normally operated by two persons per shift. It is estimated that at least another two persons per shift would be needed at the separation facility, in addition to a supervisor for Alternate No. 1. For Alternate No. 2 and 3, it was assumed that three operators plus a foreman would be needed.

It is assumed that all three separation options would not require any intermediate pumping and piping facilities. The following optimum conditions were also used:

Primary Dredge Size	24-inch
Primary Dredge Solid Concentration	10%
Secondary Dredge Rate	2000 gpm
Secondary Dredge Solids Concentration	70%

The analysis does not include any benefits accruing from the sale of sand and gravel for construction uses, such as building material or for paving, fill, railroad ballast, etc.

3. TRANSPORTATION

Table IV-17 presents several alternate costs for transporting dredged material. The volumes in the table are based on material from alternate depths at a one-acre site. The table shows the alternate costs involved to haul material 1, 10, 50, 1000, and 500 miles. It was assumed that 10 cubic yard trucks would be typically used for the short haul of one mile and that 20 cubic yard trucks would be utilized for the longer distance.

4. ELUTRIATE TREATMENT

The costs associated with elutriate treatment are too numerous to include in this report. Ample information on this subject is available in the literature. The EPA has three publications:

- (1) Construction Costs for Municipal Wastewater Treatment

TABLE IV-14
DREDGING PROJECT COSTS

<u>PROJECT</u>	<u>QUANTITY</u> (cu.yds)	<u>COST</u> (\$/cu.yd)
I Back Bay Fens, Boston, Mass. (1976) Dredging and Degritting Demonstration Project	7,000	\$ 1.75
II Hampton Roads, Va. (1980) Dredging and Barge Disposal	1,000,000	1.39
III Coal Pier, Va. (1980) Clamshell Dredging	75,000	3.29
IV Mooring Facilities, Norfolk, Va. (1979)		
Dredging Site A	39,000	4.05
Dredging Site C	24,000	2.25
V Portland, Maine (1980)		
Hydro-Dredge with Ocean disposal	857,000	2.59

Note: Above figures do not include costs for treatment of dredged material.

TABLE IV-15

INITIAL CAPITAL COSTS FOR ALTERNATE METHODS OF DRILLED MATERIAL SEPARATION
(24-INCH DREDGE, 10 PERCENT SOLIDS)

Equipment/Facility Items	SEPARATION BASINS WITH SECONDARY DREDGE		HYDRAULIC SCALPING FOLLOWED BY HYDROCYCLONE		HYDRAULIC THICKENING WITH HYDRAULIC SCALPING	
	Units	Costs	Units	Costs	Units	Cost
A. Separation Basins						
1. Land Cost	.3 acres	\$ 3,000	N.A.	N.A.	N.A.	N.A.
2. Construction Cost	2860 ft.2	15,000	-	-	-	-
3. Subtotal	-	18,000	-	-	-	-
B. Secondary Dredge						
1. Grizzlies and Screens	2000 gpm	25,000	N.A.	N.A.	N.A.	N.A.
2. Scalpers and Classifiers	1012ftx48ft.	40,000	-	-	-	-
3. Spiral Classifiers	2040in. double	75,000	-	-	-	-
4. Structure	-	50,000	-	-	-	-
5. Installation	-	100,000	-	-	-	-
6. Subtotal	-	290,000	-	-	-	-
C. Hydrocyclones	N.A.	N.A.	17,000 gpm	\$ 50,000	Double Box	\$ 15,000
1. Assemblies	-	-	2012ftx48ft	80,000	2020x10	50,000
2. Spiral Classifiers	-	-	2040in. double	75,000	2040in. double	75,000
3. Installation	-	-	-	125,000	-	60,000
4. Subtotal	-	-	-	125,000	-	100,000
D. Hydraulic Thickener						
1. Grizzlies and Screens	-	-	-	-	-	-
2. Tank and Scraper	-	-	1205 cones	200,000	N.A.	N.A.
3. Installation	-	-	1042 in double	45,000	-	-
4. Subtotal	-	-	-	75,000	-	-
E. Conveyors and Elevators						
1. Equipment Cost	-	-	N.A.	N.A.	-	-
2. Installation	-	-	-	-	-	-
3. Subtotal	-	-	-	-	-	-
F. Total Costs		\$ 518,000		\$ 825,000		\$ 530,000

Source: Corps of Engineers Report No. DACW 39-73-C-0136 by Hitmen Assoc.
Updated costs by CE Maguire, Inc.

TABLE IV-16
OPERATION AND MAINTENANCE COSTS OF ALTERNATE METHODS OF DREDGED MATERIAL SEPARATION
(24-INCH DREDGE, 10 PERCENT SOLIDS)

	1. <u>Separation Basin with Secondary Dredge</u>	2. <u>Hydraulic Scalping Followed by Hydrocyclone</u>	3. <u>Hydraulic Thickeners with Hydraulic Scalping</u>
Labor Costs	\$1280/Day	\$1040	1040
Maintenance and Repair	70	55	55
Power and Fuel	50	33	25
Misc. Insurance, Taxes Permits, Fees	40	40	40
TOTAL	<u>\$1440/Day</u>	<u>\$1168/Day</u>	<u>\$1160/Day</u>

TABLE IV-17
TYPICAL TRANSPORTATION COSTS
PER ACRE OF DEPOSITS

Dredging Depth	Total Transportation Cost/Acre				
	1 mile	10 mile	50 mile	100 mile	500 mile
1 Ft.	\$ 97	\$ 484	\$ 2,421	\$ 4,842	\$ 24,210
5 Ft.	\$ 404	\$ 2420	\$ 12,102	\$ 24,204	\$ 121,020
10 Ft.	\$ 968	\$ 4840	\$ 24,201	\$ 48,402	\$ 242,010

Dredging Depth	Labor Costs/Acre				
	1 mile	10 mile	50 mile	100 mile	500 mile
1 Ft.	\$ 1,440	\$ 2,400	\$ 6,480	\$ 9,600	\$ 64,400
5 Ft.	\$ 6,960	\$12,000	\$ 32,160	\$ 48,480	\$ 322,800
10 Ft.	\$13,920	\$24,240	\$ 64,560	\$ 96,720	\$ 645,200

Dredging Depth	Total Hauling Costs/Acre (Dollars)				
	1 mile	10 mile	50 mile	100 mile	500 mile
1 Ft.	\$ 1,537	\$ 2,884	\$ 8,901	\$ 14,442	\$ 88,610
5 Ft.	\$ 7,364	\$14,420	\$ 44,262	\$ 72,689	\$ 443,820
10 Ft.	\$14,888	\$29,080	\$ 88,761	\$145,122	\$ 887,210

Plants, MCD-37, January 1978.

- (2) Construction Costs of Municipal Wastewater Conveyance Systems, MCD-38, May 1978.
- (3) Analysis of Operation and Maintenance Costs for Municipal Wastewater Treatment Systems, MCD-39, February 1978.

The type and degree of elutriate treatment will depend upon many factors when applied to dredge spoil from the Blackstone River or any other water course. These factors should not only reflect the quantity and quality of the deposits themselves, but also the types of disposal/reuse of the elutriate and the solids.

5. DISPOSAL OF DREDGE SPOIL

Finally, we have reproduced and included several curves that have recently been published from the Noyes Data Corporation entitled, "Landfill Disposal of Hazardous Wastes and Sludges." According to his reference the source of the data is EPA Document No. EPA-625/4-78-012.

The criteria used for the various landfilling methods in Figures IV-13 to Figure IV-15 are shown in Table IV-18. The data is based on wet tons of sludge received at the disposal site each day. Capital costs include: land, site preparation, equipment purchase, and engineering, and, according to the author, were updated to reflect 1978 costs.

The life of the landfill rate was 5 years. Land costs were assumed at \$2,500 per acre. Fill areas consumed 50% of the total site area. Engineering was 6% of the total capital costs and operating labor costs of \$8.00 per hour, including fringe, overhead and administration were used. Operating costs include: labor, equipment fuel, maintenance and parts, utilities, laboratory analysis of water samples, and supplies and materials. It should be noted that the costs of groundwater sampling

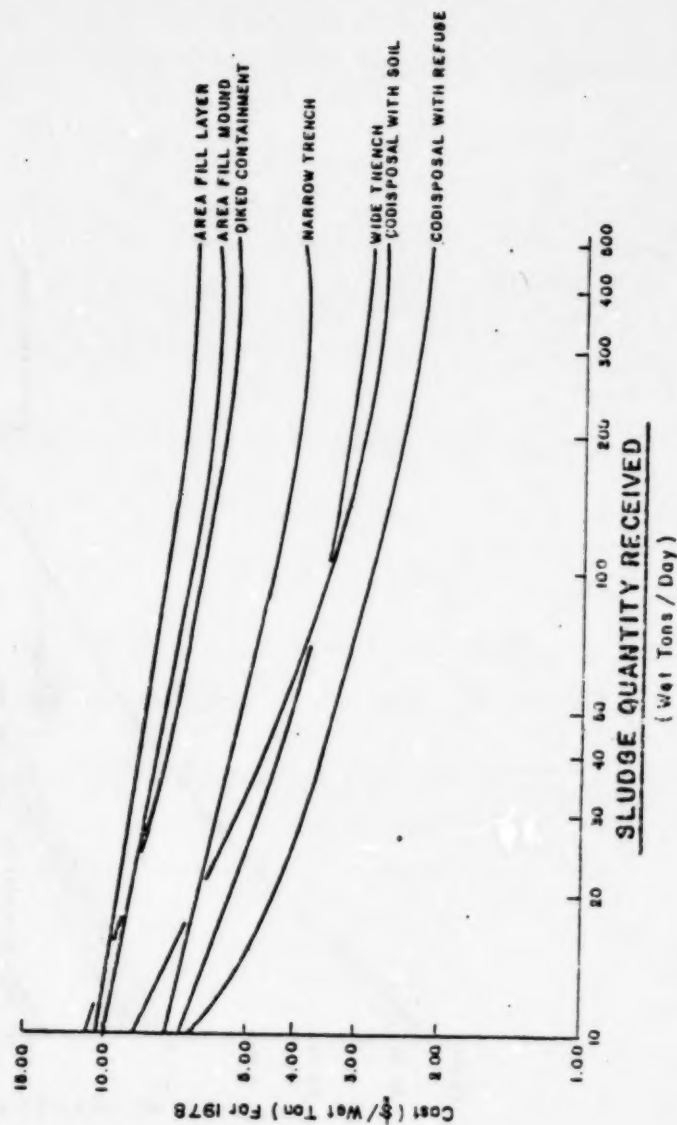
TABLE IV-18

COST SCENARIOS FOR ALTERNATIVE LANDFILLING METHODS

Cost Scenario Number	Landfilling Method	Sludge solids content (percent)	Width (Ft)	Depth (Ft)	Length (Ft)	Spacing (Ft)	Bulking per-formed	Bulking Agent	Bulking Ratio	Sludge depth per lift (ft)	Number of lifts	Sludge application rate (yd ³ /acre)
1	Narrow Trench	22	6	6	100	9	No	---	---	4	1	2,580
2	Wide Trench	32	60	8	600	30	No	---	---	4	1	4,100
3	Area Fill Mound	30	--	--	---	--	Yes	Soil	1 soil:	6	2	9,680
4	Area Fill Layer	30	--	--	---	--	Yes	Soil	1 sludge	2	2	4,300
5	Diked Containment	25	50	30	100	30	Yes	Soil	0.5 soil:	6	4	12,410
6	Sludge/Refuse mix.	20	--	--	---	--	Yes	Refuse	1 sludge	6	3	2,520
7	Sludge/Soil mixture	20	--	--	---	--	Yes	Soil	7 Tons ref: 6 1 wet ton sl.	1	1	1,600
									1 soil:	1		
									1 sludge			

Cost Scenario Number	Landfilling Method	Sludge solids content (percent)	Cover applied	Location equipment	Cover thickness		Imported Soil required	Miscellaneous
					Interim (Ft)	Final (Ft)		
1	Narrow Trench	22	Yes	Land-based	---	4	No	Backhoe with loader, track dozer, exc
2	Wide Trench	32	Yes	Sludge-based	---	5	No	Track loader, scraper, track dozer
3	Area fill mound	30	Yes	Sludge-based	3	1	Yes	Track loader, backhoe, track dozer, scraper, wheel loader
4	Area fill layer	30	Yes	Sludge-based	0.5	1	Yes	Track dozer, scraper, grader, wheel loader
5	Diked containment	25	Yes	Land-based	1	3	Yes	Dragline, track dozer, scraper
6	Sludge/refuse mix.	20	Yes	Sludge-based	0.5	2	No	Track dozer, truck loader
7	Sludge/soil mixture	20	No	Sludge-based	---	--	No	Tractor with disc. grader, track loader

Source: EPA Document No. EPA-625/4-78-012 and "Landfill Disposal of Hazardous Wastes and Sludge", Noyes Data Corp., M. Sittig, 1979.

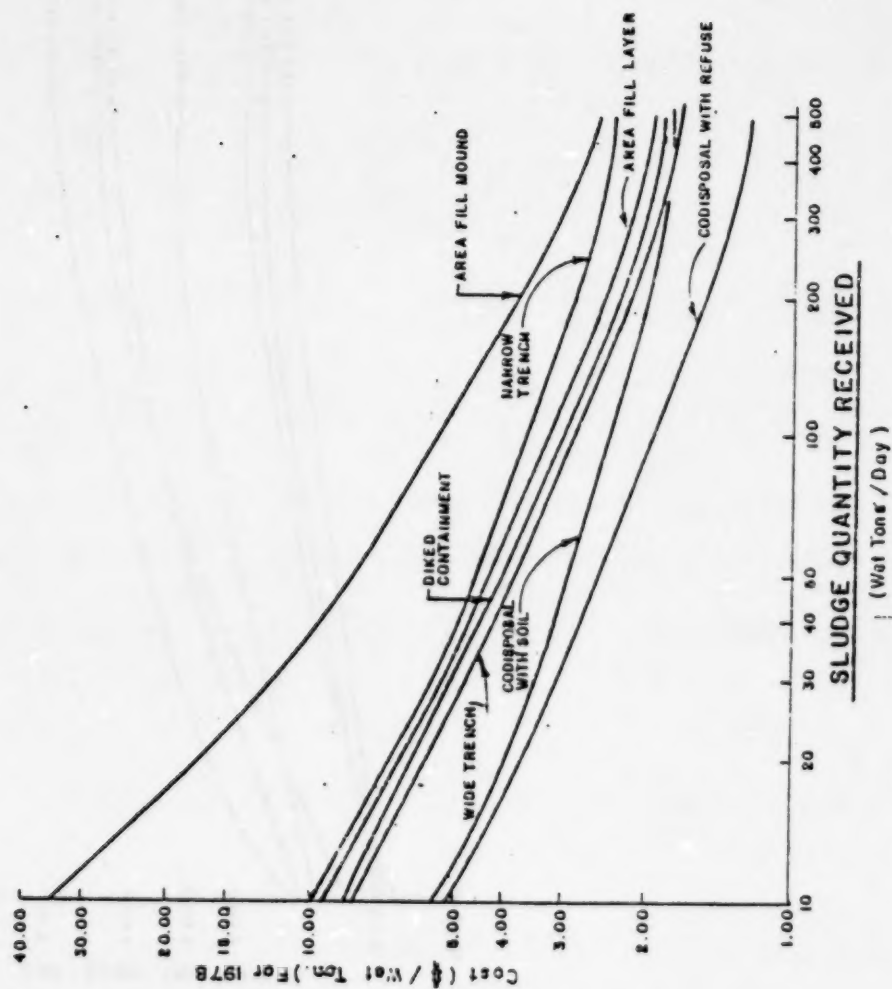


SOURCE: E.P.A. Document No. E.P.A.-625/4-70-012 and "LANDFILL DISPOSAL HAZARDOUS WASTES AND SLUDGES", Sillig, 1979

REPORT ON BLACKSTONE RIVER SEDIMENT CONTROL AND REMOVAL

FIGURE IV-13

TYPICAL ANNUALIZED SITE CAPITAL COST

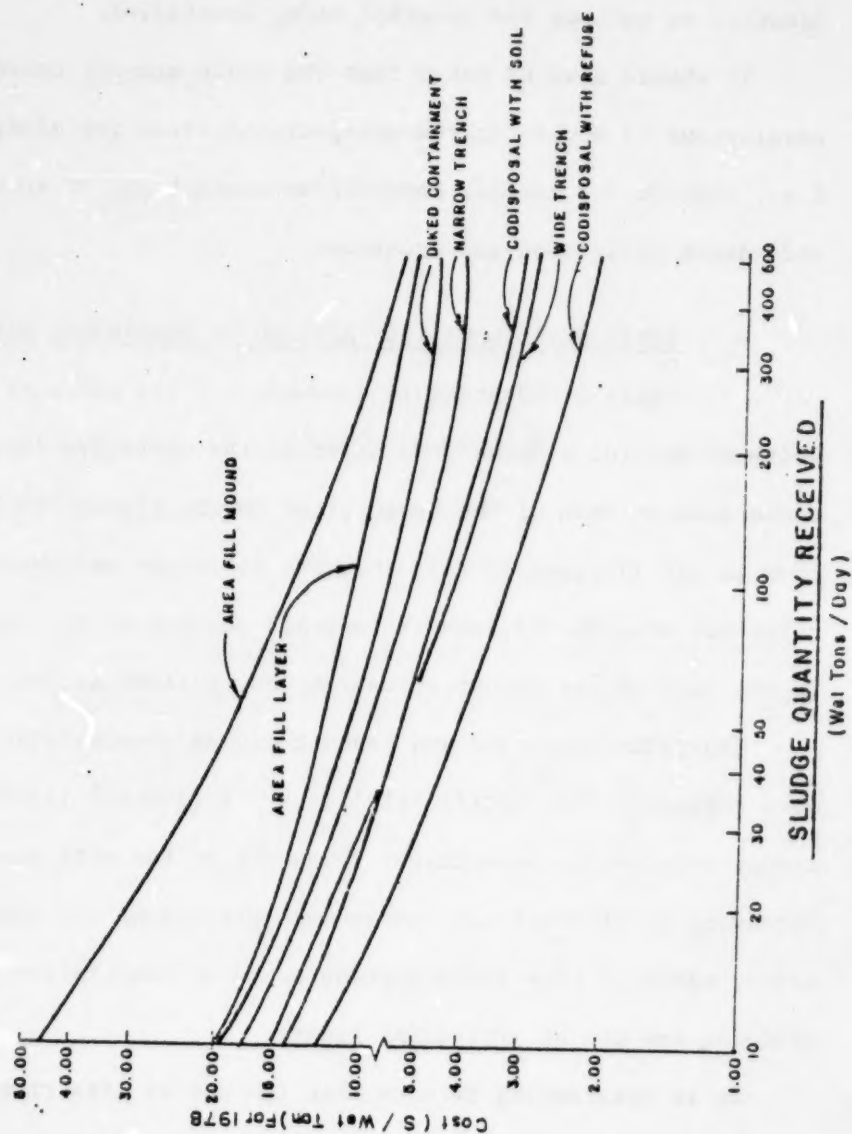


SOURCE: E.P.A. Document No. E.P.A. - 625/4-78-012 and "LANDFILL DISPOSAL HAZARDOUS WASTES AND SLUDGES", Sept. 1978

REPORT ON
BLACKSTONE RIVER
SEDIMENT CONTROL AND REMOVAL

FIGURE IV-14

TYPICAL SITE OPERATING COST



SOURCE: E.P.A. Document N° E.P.A.-625/4-78-012 and "LANDFILL DISPOSAL HAZARDOUS WASTES AND SLUDGES", Sept. 1979

REPORT ON
BLACKSTONE RIVER
SEDIMENT CONTROL AND REMOVAL

FIGURE IV-15

TYPICAL TOTAL SITE COST
(COMBINED ANNUALIZED CAPITAL & OPERATING COST)

and analysis can vary greatly, depending upon the type and size of the landfill as well as the material being landfilled.

It should also be noted that the costs are not based upon the development of sophisticated encapsulated sites for sludge disposal, i.e., they do not include concrete encasement and/or special liners or underdrain collection and treatment.

D. COSTS OF ALTERNATIVES APPLIED TO BLACKSTONE RIVER STUDY SITES

Table IV-19 presents a summary of the costs of the various sediment control alternatives based on the operative characteristics enumerated at each of the seven sites on the Blackstone River. Lackey Pond is not included in this analysis as it was selected primarily as a reference site and because the overall quality of the sediment and water in the pond do not appear to warrant any further action.

Generally, concrete and asphalt lining/encapsulation is considerably more expensive than artificial liners. Artificial liners and dredging appear relatively competitive, depending on the site characteristics. Depending on ultimate site management objectives and application requirements, costs of lime stabilization could be competitive with both dredging and use of artificial liners.

It is interesting to note that the use of lime stabilization for a ten foot depth requirement and a lime content of 15% makes either the concrete or asphalt liner/encapsulation alternatives cost-competitive at certain sites. As pointed out in the preceding section, slope protection will almost certainly be required in conjunction with any of the alternatives considered. The selection of which slope protection alternative to be used will also depend on individual site requirements and ultimate management objectives. Based on cost alone, none of the alternatives presented can or should be dropped from consideration.

TABLE IV-19

Summary of Costs of Sediment Control Alternatives Applied to Study Sites on the Blackstone River

Site No.	SITE CHARACTERISTICS				LINER/ENCAPSULATION		
	Surface Area (Acres)	Reach Length (feet)	Surface Perimeter (feet)	Sediment Volume (Cu.Yd.)	Artificial Liner	Concrete Cover	Asphalt Cover
1	1.4	1,360	1,400	250	\$ -	\$ -	\$ -
2	2.2	1,000	1,380	4,700	\$ 222,640	1,673,256	651,048
3	.34	5,400	8,300	260,000	3,440,800	25,897,414	10,061,654
4	87.4	6,400	9,200	780,000	8,877,880	66,473,905	25,864,369
5	33.4	6,700	7,000	215,000	3,380,080	25,703,071	9,884,095
6	37.4	6,300	6,000	225,000	3,784,880	28,445,355	11,067,819
7	84	8,700	10,003	525,000	8,500,800	63,887,964	24,858,200

TABLE IV-19 (continued)

Summary of Costs of Sediment Control Alternatives Applied to Study Sites on the Blackstone River

Site No.	LIME STABILIZATION											
	1 foot depth			5 foot depth			10 foot depth			10 foot depth		
	5% Content	10% Content	15% Content	5% Content	10% Content	15% Content	5% Content	10% Content	15% Content	5% Content	10% Content	15% Content
1	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 251,971	\$ 369,375	\$ 486,7
2	18,674	37,154	55,480	303,708	395,954	488,200	395,954	580,446	764,93	395,954	580,446	764,93
3	288,592	574,192	897,412	4,693,666	6,119,286	7,574,706	4,693,666	6,119,286	7,574,706	6,119,286	8,970,526	11,821,7
4	741,851	1,476,011	2,204,053	12,065,483	15,730,165	19,397,847	12,065,483	15,730,165	19,397,847	15,730,165	23,059,529	30,388,8
5	283,499	564,059	842,281	4,610,837	6,011,299	7,411,761	4,610,837	6,011,299	7,411,761	6,011,299	8,812,223	11,613,1
6	317,451	631,611	943,153	5,163,033	6,731,215	8,299,397	5,163,033	6,731,215	8,299,397	6,731,215	7,867,579	13,003,9
7	712,992	1,418,592	2,118,312	11,596,116	15,118,236	18,640,356	11,596,116	15,118,236	18,640,356	15,118,236	22,162,476	29,206,7

TABLE IV-19 (continued)

Summary of Costs of Sediment Control Alternatives Applied to Study Sites on the Blackstone River

Site No.	DREDGING			<u>TOTAL</u>
	<u>Removal</u>	<u>Separation</u>	<u>Hauling</u>	
1	\$ 1,000	\$ 825,000	\$ 1,400	\$ 827,400
2	18,800	825,000	26,000	869,800
3	1,040,000	825,000	1,738,000	3,603,000
4	3,120,000	825,000	4,314,000	8,259,000
5	860,000	825,000	1,189,000	2,874,000
6	900,000	825,000	1,244,000	2,969,000
7	2,100,000	825,000	2,903,000	5,828,000

TABLE IV-19 (continued)

Summary of Costs of Sediment Control Alternatives Applied to Study Sites on the Blackstone River

Site No.	SLOPE PROTECTION							
	Stone Blanket		Timber Sheeting		Steel Sheeting		Retaining Wall	
	5'	10'	5'	10'	5'	10'	5'	10'
1	\$ -	\$ -	\$ -	\$ 251,600	\$ -	\$ 333,200	\$ -	\$ 603,220
2	73,529	102,475	125,000	185,000	183,000	245,000	-	443,397
3	397,057	553,365	675,000	999,000	988,200	1,323,000	1,706,448	2,394,344
4	-	655,840	-	1,184,000	-	1,568,000	-	2,887,741
5	-	686,583	-	1,239,500	-	1,641,500	-	2,970,760
6	463,233	695,593	787,500	1,165,500	1,152,900	1,543,500	1,990,857	2,792,401
7	-	891,533	-	1,607,500	-	2,131,500	-	3,857,559

V. Recommended Sediment Control Plan

A. Management Objectives

In order to evaluate the applicability of the various sediment control measures at each of the sites, it is necessary to first define the management objectives for each site. Management objectives can be defined as the desired end result of an action or series of actions. In the case of the Blackstone River, the overall end result or management objective of a sediment control plan might be, in general, to reduce or eliminate the effects of sediment polluted with heavy metals and subsequently, to recover the fisheries and wherever possible, other recreational and functional uses of the river which are presently lost due to those effects. Similarly, management objectives can be stated for each site. These objectives, which are outlined in the following sections, were assembled based on discussions with various state agencies, local government officials, and local/regional organizations as well as previous and on-going recreation and water quality planning reports. By evaluating the ability of the various control alternatives to achieve the stated objectives, a management plan for each site can be developed which should be both effective and cost-efficient.

Site 1

Management objectives for Site 1 include the following:

1. Maintain channel characteristics to ensure flow characteristics and prevent flooding.

Site 2

1. Maintain channel characteristics to ensure flow characteristics and prevent flooding.
2. Limit or halt stream bank erosion.
3. Provide cover to improve fish habitat.

Site 3

1. Limit or halt stream bank erosion.
2. Restore main channel to a depth of 8-12 feet to improve fish habitat and provide additional flood storage.
3. Reduce amount of organic matter and heavy metals to improve quality conditions for fisheries and improve recreation potential of area.

Site 4

1. Restore Fisherville Pond for recreational use.
2. Improve channel characteristics and flood storage capacity behind Fisherville Dam.

Site 5

1. Recover use of site for suitable purpose(s). (e.g. recreation, commercial, light industry, etc.).
2. Prevent release/exposure of low-pH/high metal-containing material contained within the site to the river and surrounding environment.
3. Eliminate/minimize the potential for metal leaching to reduce/eliminate toxic effects on aquatic life.
4. Limit or halt stream bank erosion.
5. Maintain channel characteristics to prevent flooding.

Site 6

1. Recover use of site for suitable purpose(s).
2. Prevent release/exposure of low pH/high metal-containing material contained within the site to the river and surrounding environment.

3. Eliminate/minimize the potential for metal leaching to reduce/eliminate toxic effects on aquatic life.
4. Limit or halt stream bank erosion.
5. Maintain channel characteristics to prevent flooding.

Site 7

1. Restore Rice City Pond for recreational use.
2. Reduce/eliminate toxic effects of heavy metals.
3. Improve fisheries habitat.
4. Improve channel characteristics to improve stream flow and flood storage.

Site 8

1. Maintain Pond for existing uses.

B. Evaluation of Alternatives and Recommended Management Plan

Each alternative control measure was evaluated with regard to meeting the stated management objectives for each site. Recommended plans for each site are based on the ability of a control measure to achieve the management objectives, in addition to the costs and perceived impacts associated with the control measure. The recommended sediment control plans for each site, together with the rationale and estimated costs, are described in the following sections:

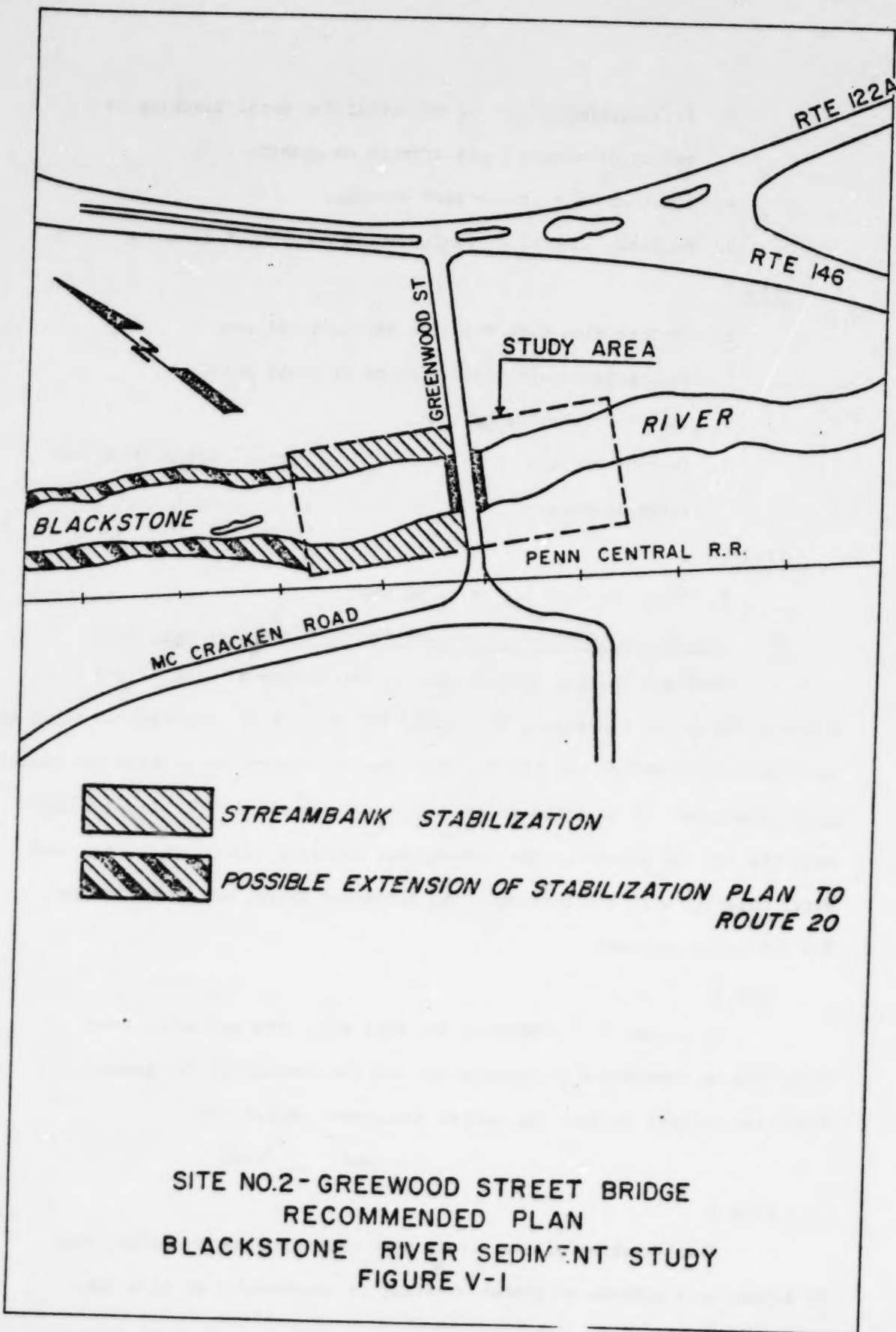
Site 1

No action is recommended for this site. The pollution level at this site is considered relatively low and the channel in its present condition appears to meet the stated management objectives.

Cost: \$0.00

Site 2

Stabilization of the stream bank upstream from McCracken Pond by either rock gabions or timber sheeting is recommended at this site.



Based on future site investigations, this recommendation might be extended as far as Route 20.

Of the two methods of stabilization proposed, rock gabions are preferable as over a period of time, they will be able to hold vegetation which will become a source of food and provide cover for fish. Also, rock gabion is slightly less expensive than timber sheeting.

Cost: Rock Gabion: \$102,475 (Recommended Alt.)

 Timber Sheeting: \$185,000

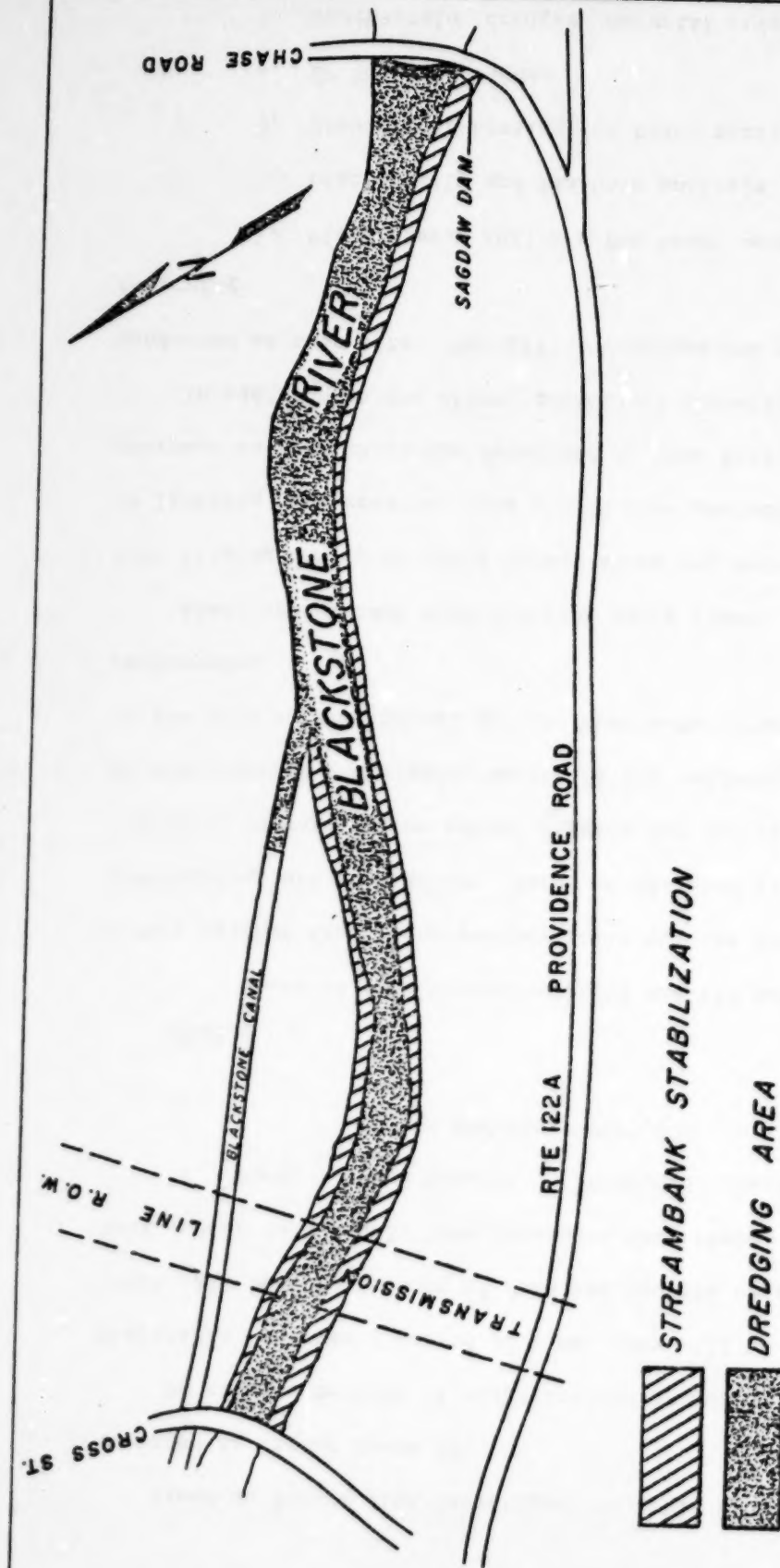
Site 3

Based on site characteristics and the extent of vegetative cover, neither the liner/encapsulation nor the lime stabilization alternatives are applicable. Based on the need to both increase the available storage volume behind Singing Dam and to reduce the levels of heavy metals and organic matter in the sediments, dredging, limited to the main stream channel and the open-water area behind the dam, is recommended.

Also, stream bank stabilization using timber sheeting is recommended from Singing Dam up to Cross Street along the westerly bank. In addition to limiting bank erosion, this should also protect and enhance the emergent wetland which has developed in that area.

In addition to the above, additional investigations should be conducted at this site. Specific investigations should include the following:

1. Plant tissue analysis for heavy metals.
2. Leachability and leachate analysis.
3. Groundwater testing for heavy metals.
4. EP Toxicity Tests.
5. Bench-scale dredged material treatability evaluations.



SITE NO.3 - SAGDAW DAM
RECOMMENDED PLAN
BLACKSTONE RIVER SEDIMENT STUDY
FIGURE V-2

6. Bioassays and resident species tissue analysis for heavy metals.

In conjunction with the recommendation for dredging, it is recommended that a feasibility study be conducted to determine which type of dredge should be used; the method of dredged material treatment and disposal; the location(s) for dredged material treatment and disposal and; the sedimentation control measures to be utilized during the dredging operation to protect downstream water quality. The proximity of gravel pits and the Millbury wastewater treatment plant should be considered in this aspect.

Cost:	Dredging:	\$3,603,000
	Timber Sheeting:	999,000
	Total	\$4,602,000

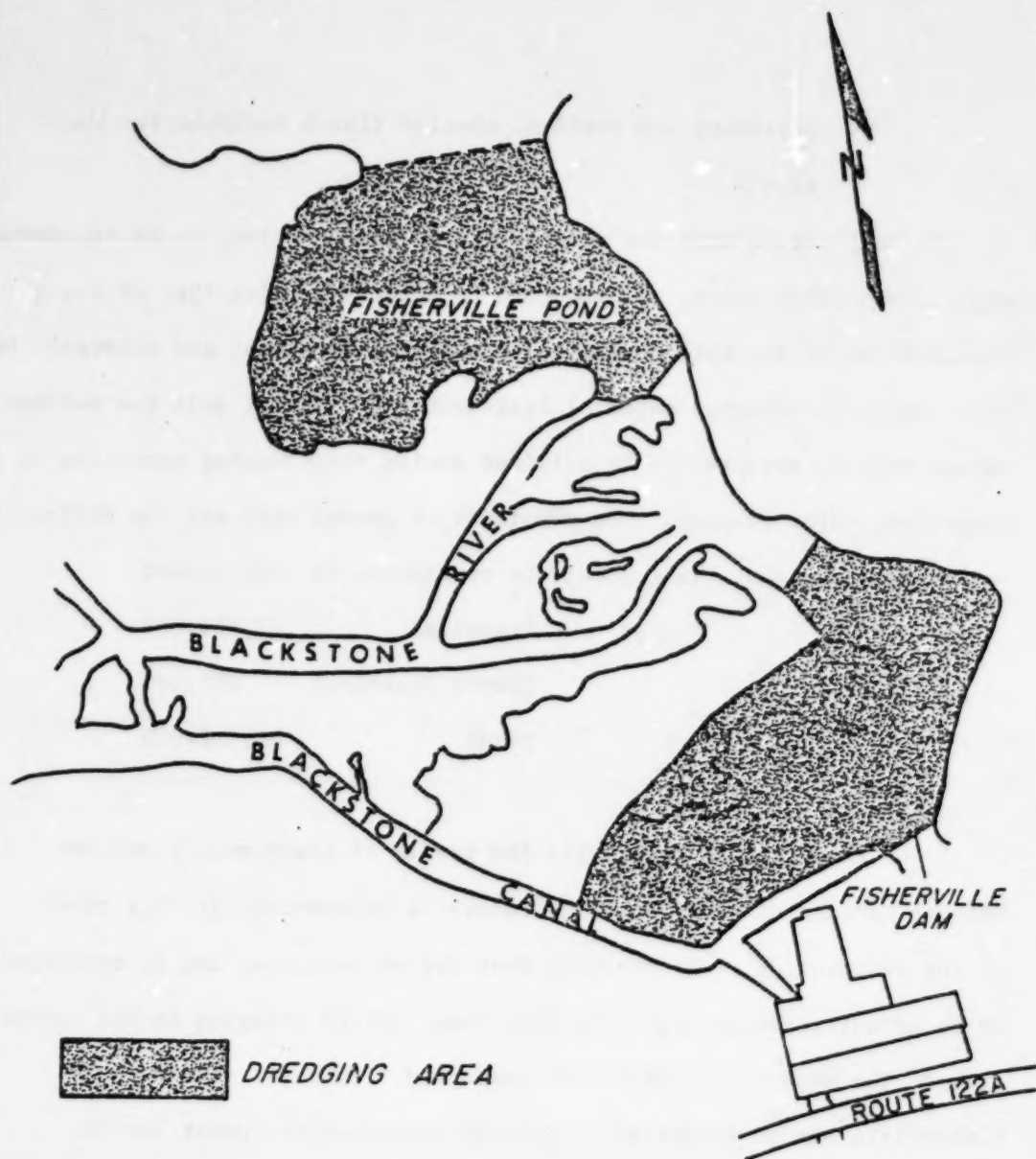
Site 4

Based on the relatively low levels of heavy metals and low SPI, no action with regard to sediments is recommended at this time. If the restoration of Fisherville Pond for recreational use is determined to be of sufficiently high priority, then limited dredging in the northern area of the pond will probably be warranted. Further, should the Fisherville Dam be converted to provide hydroelectric power for the existing factory, then dredging will also be required to provide additional storage behind the dam.

Cost: \$0.00

Site 5

Although dredging is the least-cost alternative applicable to this location, dredging is not recommended, as one of the primary management objectives is to recover the site for some suitable beneficial purpose. Liner/encapsulation alternatives, although somewhat cost-competitive with



SITE NO.4 - FISHERVILLE DAM
RECOMMENDED PLAN
BLACKSTONE RIVER SEDIMENT STUDY
FIGURE V-3

lime stabilization, are not considered effective due to the depth of contaminated sediment and with regard to their inability to control leaching via groundwater. Lime stabilization using five and ten foot columns as determined necessary, is therefore recommended. It is further recommended that additional testing including the following be undertaken prior to implementation:

1. Groundwater analysis.
2. Geotechnical investigations including bearing capacity, slope stability, shear angles, cohesiveness, compressive strength and additional soils analysis.
3. Leachability and leachate analysis.
4. Bench-scale laboratory studies to determine lime requirements.
5. Preliminary small-scale evaluation of lime column technique.

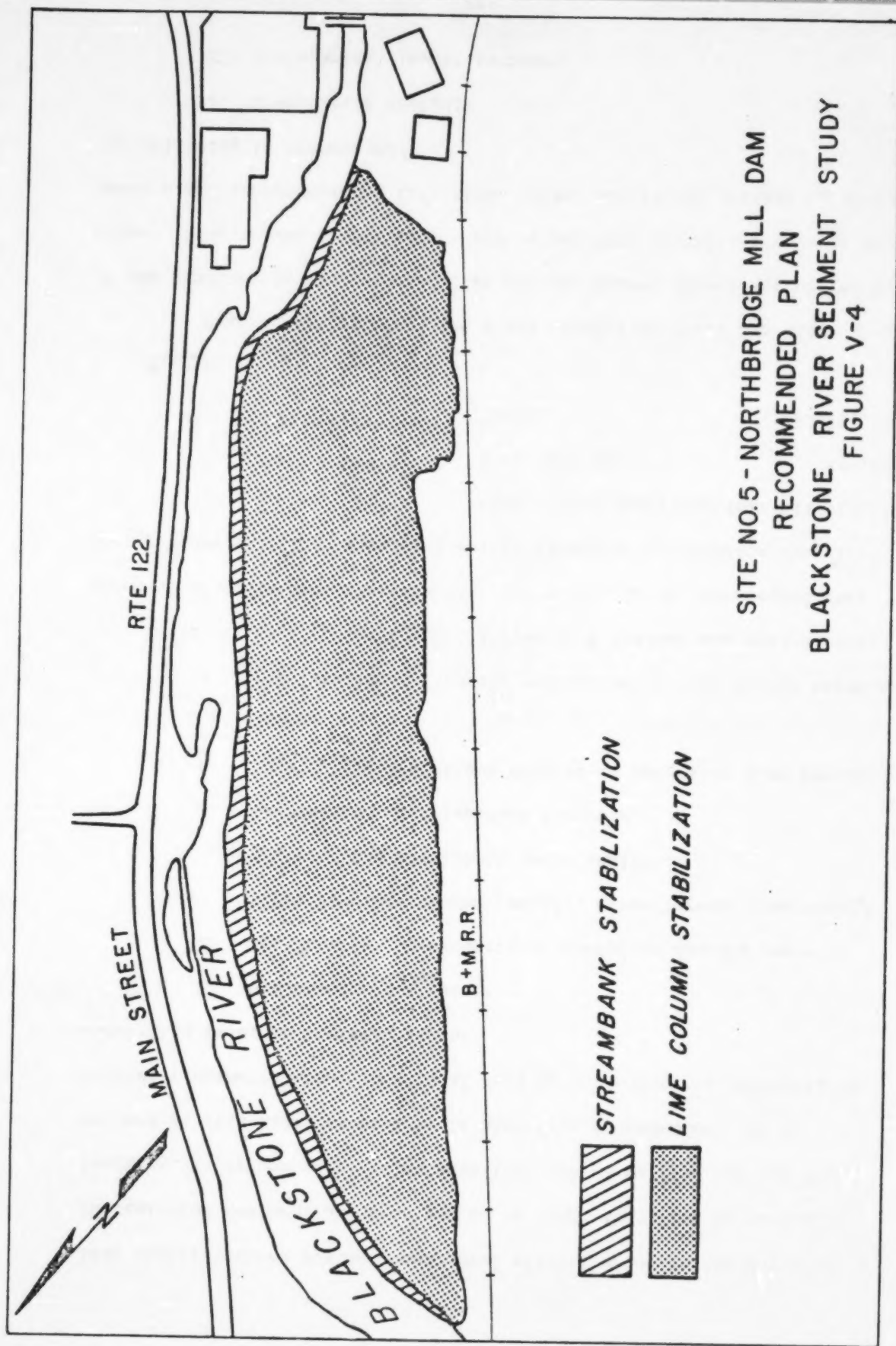
In addition, in order to halt stream bank erosion and prevent mass movement of soils from the site into the river, it is recommended that rock gabions be placed along the entire riverbank surrounding the site.

Cost:	Lime column stabilization:	\$11,613,147
	Rock Gabions	686,583
	Total	\$12,299,730

Site 6

Recommendations for site 6 are similar to those for site 5 based on the similarities in the character and management objectives of the two sites. Lime column stabilization and stream bank stabilization with rock gabions are recommended at this site. Also, additional testing to include the following is recommended:

1. Groundwater analysis
2. Geotechnical investigations



3. Leachability and leachate analysis.
4. Bench-scale studies to determine lime requirements.
5. Preliminary small-scale evaluation of lime column technology.

Cost:	Lime Column Stabilization	\$13,003,943
	Rock Gabions	645,593
	Total	\$13,649,536

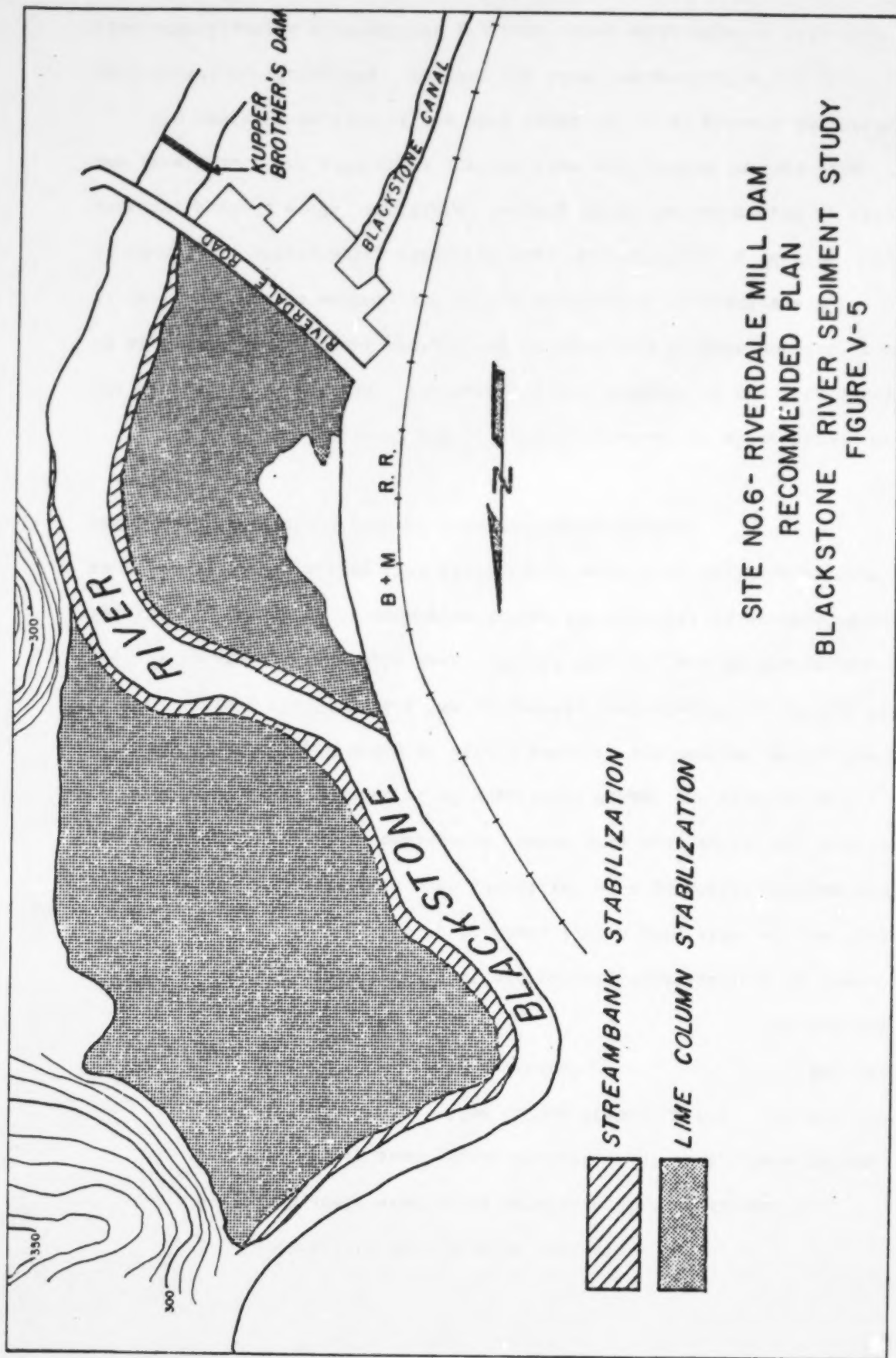
It is further recommended that additional investigations be conducted on areas upstream from site 6 up to Route 122 on both sides of the river. This area had not previously been identified as a potential problem area. However, recent aerial reconnaissance showed this area to be very similar to both sites 5 and 6 in terms of vegetative damage and appearance.

A further consideration at site 6 involves the current evaluation of re-constructing the Riverdale Dam to provide hydroelectric power for the factory located on Riverdale Road. Should this project be determined feasible, it would be necessary to dredge the material to provide required storage volume and either lime stabilize or otherwise seal the exposed underlying material to prevent leachate contamination.

Site 7

Similar to sites 3 and 4, liner/encapsulation alternatives are not considered applicable. The northeastern quadrant of the site (area 7A) is at present an emergent wetland and is host to a sizable population of birds, reptiles and mammals and offers substantial recreation use in terms of education, photography, bird-watching, etc. and hunting (during appropriate seasons, posted, etc). Additional testing should be undertaken to determine the feasibility and effects of surface lime application in this area.

The southern portion of the pond (area 7B) is at present depth-limited with regard to recreation. Neither the liner/encapsulation nor the lime stabilization alternatives are considered applicable in this area.



Dredging is therefore recommended. Concomittant with this recommendation, additional studies are recommended, including the following:

1. Plant tissue analysis (area 7A & 7B)
2. Leachability and leachate analysis (area 7A and 7B)
3. Bench-scale testing to determine lime requirement (area 7A).
4. Bench-scale dredged material treatability evaluations (area 7B).
5. Feasibility of using nearby gravel pits and/or Northbridge sewerage treatment plant for dredged material treatment/disposal.
6. Development of sediment control measures to be utilized during dredging operation to prevent downstream pollution problems.
7. Additional bioassays and resident species tissue analysis for heavy metals.

Cost: Area 7A: lime stabilization: (1)	\$1,868,000
Area 7B: Dredging: (2)	3,087,720
Total	\$4,955,720

(1) Based on 48.4 acres @\$38,586/acre

(2) Based on 235,700 cubic yards @ \$4.00 cu.yd. for removal; \$825,000 for separation, plus \$5.60/cu. yd. for hauling.

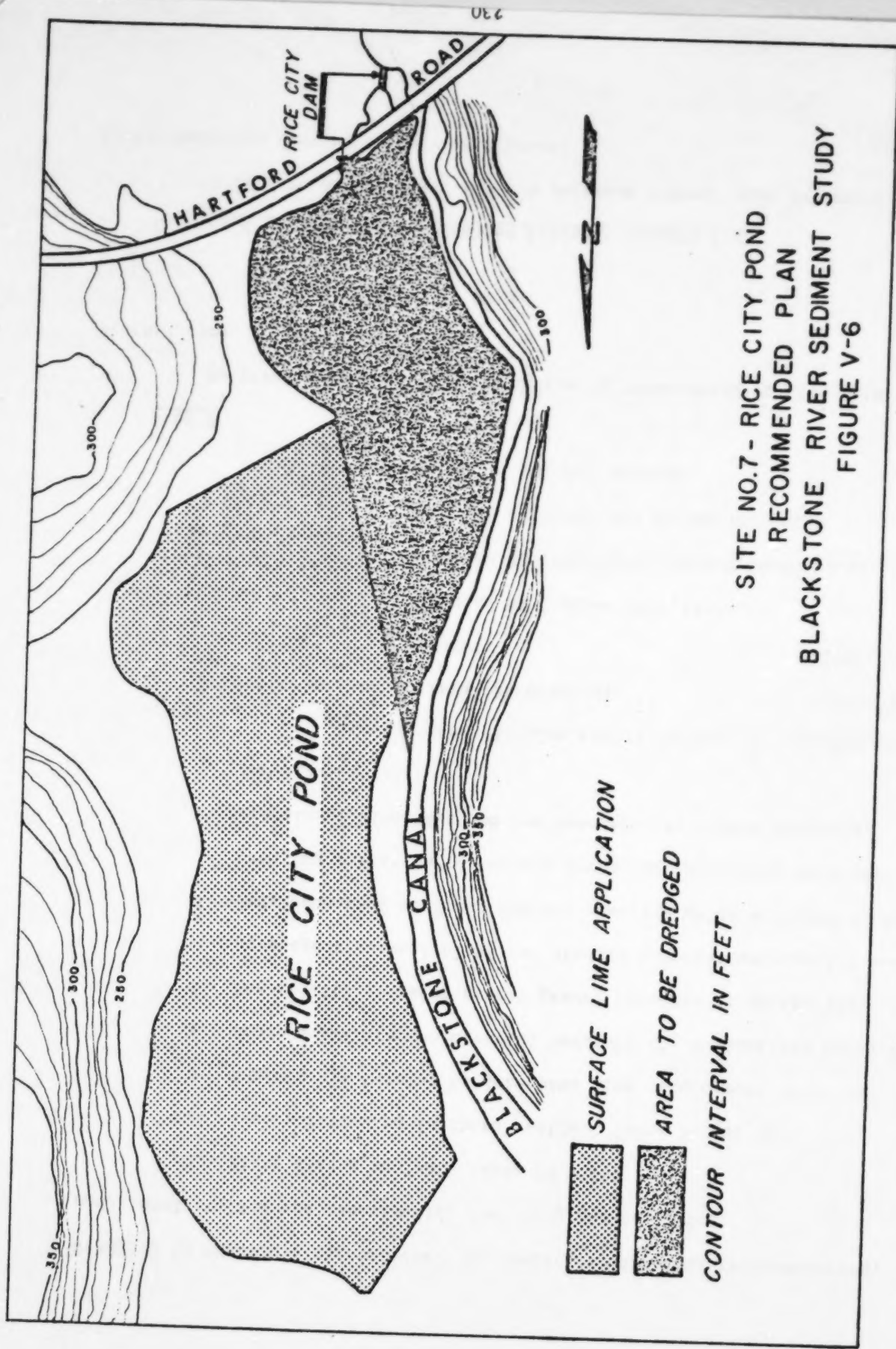
Site 8

As previously discussed, no action is recommended at this site at this time.

Cost: \$0.0

C. Cost Summary for Recommended Sediment Control Plan

A summary of the costs for the sediment control plan recommended in the previous section appears as follows:



SITE NO. 7 - RICE CITY POND
RECOMMENDED PLAN
BLACKSTONE RIVER SEDIMENT STUDY
FIGURE V-6

<u>Site</u>	<u>Total Cost</u>
1	\$ 0.
2	102,475.
3	4,602,000.
4	0.
5	12,299,730.
6	13,649,536.
7	4,955,720.
8	<u>0.</u>
Total Cost:	\$35,609,461.

It is important to reiterate at this point that these costs as presented should not be considered "final." It is conceivable, and highly likely, that, based on additional testing and site investigations conducted prior to implementation as recommended/concluded in Chapter III, and in the previous section, these costs could change considerably. This realization suggests the need for flexibility in plan implementation and phasing of various plan elements to coincide with additional studies and site investigations.

D. Agency Recommendations

Recognizing the potential role and need for involvement of several state, federal and local agencies required to implement this sediment management plan effectively, the following recommendations are made:

Department of Environmental Quality Engineering

The DEQE is the designated water quality management agency for the Commonwealth. For the purposes of this element of the overall water

quality management plan for the Commonwealth, it is recommended that the responsibility for implementation of this plan be assumed by the Division of Waterways, within the DEQE.

With regard to ancillary recommendations including additional sampling, testing, evaluations, & bioassays it is recommended that these be undertaken by the Research and Demonstration Section within the Division of Water Pollution Control of the DEQE. The program set up within the R & D section must be closely coordinated with the efforts and needs of the Division of Waterways and the U.S. Army Corps of Engineers as plan implementation proceeds.

U.S. Army, Corps of Engineers

It is recommended that, at the request of the Secretary of the Executive Office of Environmental Affairs for the Commonwealth, the U.S. Army, Corps of Engineers, through it's waterways and dredging sections, provide whatever technical and financial assistance available to enable the DEQE to implement the recommended sediment management plan.

U.S. Environmental Protection Agency

It is recommended that the U.S. Environmental Protection Agency, through it's Region I offices, continue to provide support for the implementation of this sediment management plan and to provide both technical and financial assistance as may be available. Specific assistance should be provided by the Region I Environmental laboratory to include additional sediments testing and additional bioassays as recommended in Chapter III, Section D. Conclusions earlier in this report.

Southern Worcester County Conservation District

It is recommended that the Southern Worcester County Conservation District, together with the Holden office of the Soil Conservation Service

of the U.S. Department of Agriculture, provide any technical and financial assistance available with specific regard to the stream bank stabilization elements of the recommended sediment control plan.

E. Funding and Phasing of Plan Implementations

Recognizing that funding of all or portions of the recommended sediment control plan is perhaps the major obstacle facing plan implementation, it is recommended that the implementation of the control plan be phased to occur over a period of three to five years.

Phase I of the implementation program would consist of implementing the stream bank stabilization recommendations for sites 2,3,5, and 6. (total cost: \$2,433,651). At the same time, feasibility studies on dredging and lime column stabilization elements would be conducted.

Phase II would tentatively consist of the implementation of the dredging programs at sites 3 and 7 and the surface lime stabilization at site 7 (Total Cost: \$8,558,720).

Phase III and IV would each involve one of the lime column stabilization projects at sites 5 and 6, respectively. Phase IV cost at Site 5 is \$11,613,147. Phase IV cost is \$13,003,943, for site 6.

In this manner, State and Federal funds could be appropriated on an annual basis to accomplish specific elements of the recommended sediment control plan. The annual appropriation required would be equivalent to the total cost of the phase of the program to be implemented in the following fiscal year. The annual costs can be summarized as follows:

<u>Year</u>	<u>Phase</u>	<u>Total Cost</u>
1	I	\$ 2,433,651.
2	II	8,558,720.
3	III	11,613,147.
4	IV	13,003,943.

If necessary, an additional phase could be added by separating one or more of the elements presently included in Phase II.

Sources of funding are unclear at this time due to the recent shifts in policy and funding levels at both the Federal and State levels. At this point, it is assumed that an annual appropriation from the State Legislature will be sought in combination with Federal aid through the Corps of Engineers, Soil Conservation Service, and Environmental Protection Agency. As much of the work included in the recommended control plan is based on recovery of recreational uses of the Blackstone River, the Bureau of Outdoor Recreation as well as other related agencies should be included as potential funding sources. Finally, private industry along the Blackstone should be viewed as potential funding sources, particularly where improvements to the river and its surroundings brought about through plan implementation provide direct benefits to the industries.

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